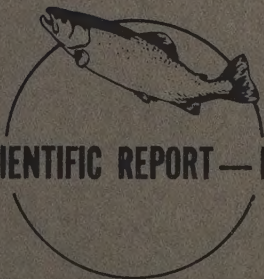
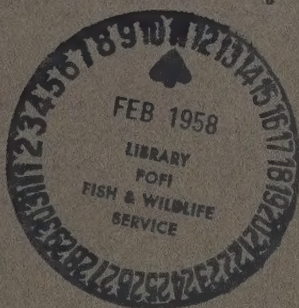


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Further Studies on Green or Offcolor Condition in Precooked Yellowfin Tuna



SPECIAL SCIENTIFIC REPORT—FISHERIES No. 247

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

Explanatory Note

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United States Department of the Interior, Fred A. Seaton, Secretary
Fish and Wildlife Service, Arnie J. Suomela, Commissioner

FURTHER STUDIES ON GREEN OR OFFCOLOR CONDITION
IN PRECOOKED YELLOWFIN TUNA

By

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Special Scientific Report--Fisheries No. 247

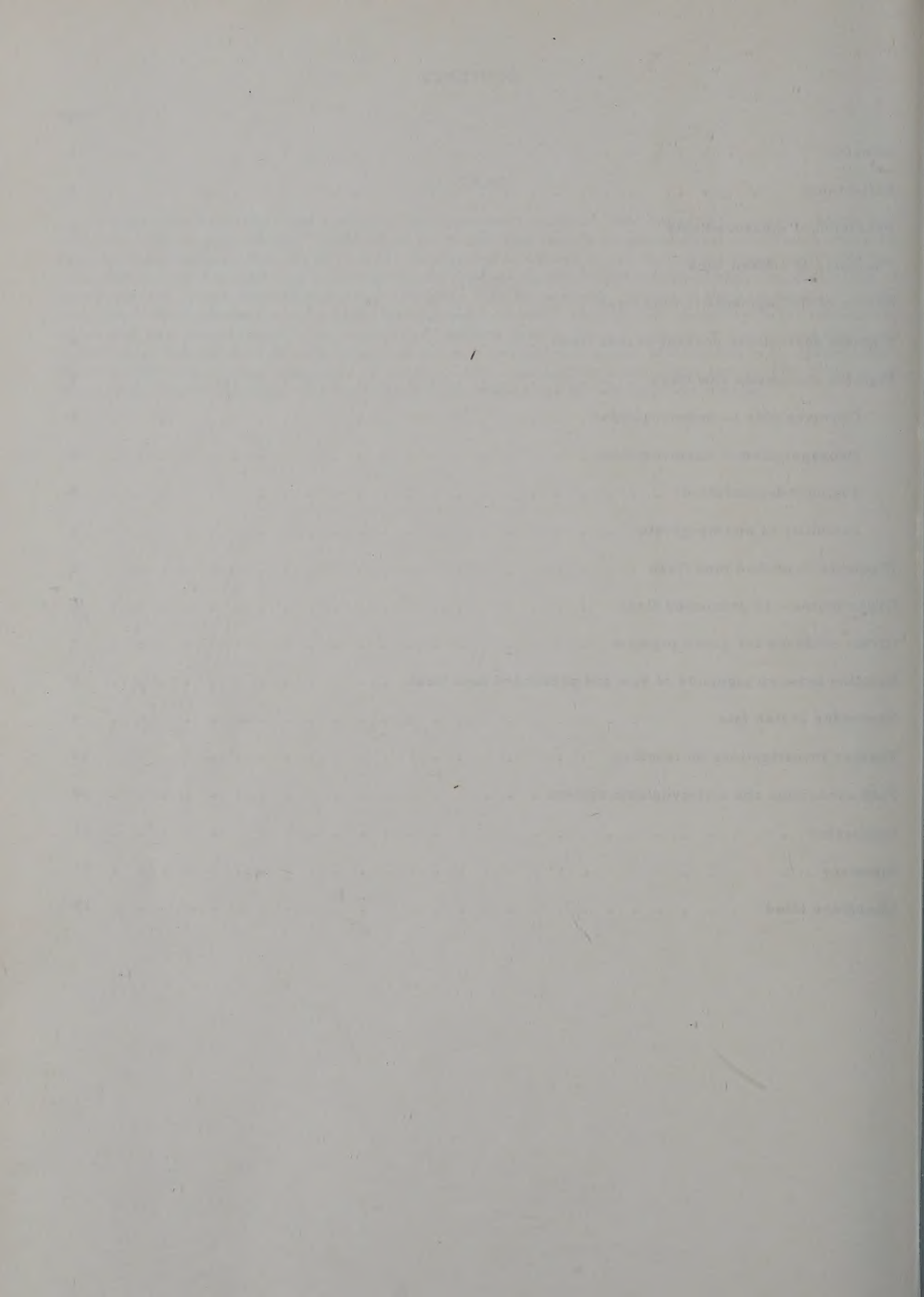
WASHINGTON: November 1957

ABSTRACT

Results are reported from a study of the "greening" condition that appears in certain samples of yellowfin tuna on precooking. Evidence is presented that this is an actual color condition similar to discoloring processes that occur in other meats, and is caused by an anomalous heme protein oxidation. Related to this tendency to turn green on precooking are the presence of high concentrations of metmyoglobin, some denaturation, and a slightly high fat peroxide content in the raw meat. In addition, green meat generally has a high flesh pigment content. Oxygen starvation due to the exhaustion of the fish that might occur in the process of catching does not seem to produce the factors that lead to greening, but rather a deterioration that goes on even in the frozen state seems to be responsible. Spectral reflectance was employed in much of the work and revealed important in situ changes or processes in flesh pigments that would have been impossible to note by other means.

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FURTHER STUDIES ON GREEN OR OFFCOLOR CONDITION IN PRECOOKED YELLOWFIN TUNA

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An undesirable "green" color which develops in the flesh of certain tuna on precooking prior to canning, results in considerable economic loss to the fisherman and to the industry through rejection of such fish. The cause of this offcolor condition has been the subject of studies at the Chemistry Department, University of Hawaii, under contract No. 14-19-008-2475 with the Pacific Oceanic Fishery Investigations (POFI), U. S. Fish and Wildlife Service. The background and the results of preliminary studies are embodied in a previous report (Naughton, Frodyma, and Zeitlin, 1956).

The extension of the work herein described represents an attempt to establish more definitely the nature and genesis of the pigment or pigments responsible for the offcolor.

We are most grateful to Mr. Fred Jermann of Hawaiian Tuna Packers, Ltd., and to Dr. Albert L. Tester, Director, and other members of the staff of POFI for suggestions and help in the investigation.

SAMPLES

The fish used in this study were yellowfin tuna (Neothunnus macropterus) which, for the most part, were caught on longline by POFI research vessels in the central equatorial Pacific in 1955 and 1956. The fish were frozen on board ship as soon as possible after capture and were held in a solid frozen condition until they were needed. Sizes ranging from about 70 to 200 pounds were selected as it had been noted that the larger fish showed a greater tendency to turn green on precooking. In addition small yellowfin (up to 15 pounds) were caught by trolling in local waters by the staff of the Hawaii Marine Laboratory, University of Hawaii, and were sampled while fresh. Samples of fresh, prime fillets ("ahi" samples) of yellowfin caught in the local longline fishery were purchased from local markets for study.

In order to obtain precooked samples for the evaluation of color, frozen fish were thawed in tanks at Hawaiian Tuna Packers, Ltd., and cut into loins; one loin from each fish was retained as a raw sample. The remaining loins were put through the regular commercial

precooking process of that company. Judgment of color grade of the precooked samples was made by Mr. Fred Jermann, the company's food technologist. Specific samples noted to be characteristic of their types (normal, green, pink, etc.) as subjectively judged, were used in much of the work.

REFLECTANCE

Early in the research on the color of tuna flesh, an opaque material, the need was recognized for a device for measuring spectral reflectance, thus making possible an objective evaluation of the actual color of the samples. A reflectance attachment to the Beckman DU spectrophotometer was secured. With the development of techniques for reflectance measurement, it became apparent that the method had unique value as an analytical tool in addition to its recognized use in the specification of color. Curves exhibiting optical absorption peaks could be obtained by spectral reflection measurements. These were characteristic of the pigments present in tuna flesh and were identical with the absorption curves obtained from transmission measurements made on the same pigments in solution. Beer's law was obeyed, thus justifying the use of absorbancy or optical density in our curve plots. The obvious advantages of being able to make measurements in situ, and on insoluble systems, such as those encountered in this research, were points that were vital. A separate communication has been published (Naughton, Frodyma, and Zeitlin, 1957) which describes in greater detail the advantages of spectral reflectance as an analytical tool, especially in biological systems.

PRECISION OF MEASUREMENTS

The variability of the pigment content throughout a sample of meat (see below) introduces a difficulty when making reflectance and pigment-content measurements on a series of samples, even from the same fish. Ground and thoroughly mixed (homogenized) samples gave readings that were reproducible to ± 0.5 percent reflectance units or within the error of the measuring instrument. On standing, however, oxidative changes took place in such samples

with consequent changes in spectral absorption. Replicate nonhomogenized samples from a given fish loin gave an average precision of ± 1.5 percent reflectance units.

THE COLOR OF COOKED TUNA

A visual examination of different samples of cooked tuna flesh immediately reveals the complexity of the color system involved. First, the variability of the absolute content of pigment in the flesh of various fish should be recognized. We have encountered variations from highly bleached meat to a very high pigment concentration with resultant abnormal redness. Whether these variations are physiological or due to postmortem changes has not been determined. Secondly, the condition of "browning" can be recognized. As usually understood, this seems to be a postmortem and even a postcooking phenomenon which is due to oxidation on exposure to atmospheric oxygen. Thirdly, the greening phenomenon, which is the main subject of this research, is observed. This is a color phenomenon that permeates the flesh of the fish; its characteristics will be described later in this report. Also an orange coloration is frequently noted which seems to occur in much the same manner as the green color. Finally, it became very evident after a modicum of work on the pigment systems of the meat that the distribution of pigment within a single fish loin was quite variable, although it might seem uniform to the eye. This was confirmed by microscopic examination which showed the pigment to be present in bands within the meat. Spectral reflectance measurements gave widely variable estimates of the amount of pigment present. Uniformity could be assured only by grinding and thoroughly mixing all the meat needed in a given sample sequence. This was not usually done, however, since finely ground meat was found to change color even when held in a frozen condition.

At the beginning of this research the reality of the green of certain offcolor samples of tuna flesh was questioned by one of the investigators. The color is of such a subtle shade and exhibits so many variations that it was supposed that the so-called greenness might be a lack of pigment. In order to test the reality of the color, the ICI (International Commission of Illumination) system of color specification was plotted for typical cooked green and normal samples. The results are shown in figure 1. It will be noted that loci of the coordinates for both samples are in a region of lightness or brightness indicative of the general light color of cooked meat. The green flesh is situated nearer the

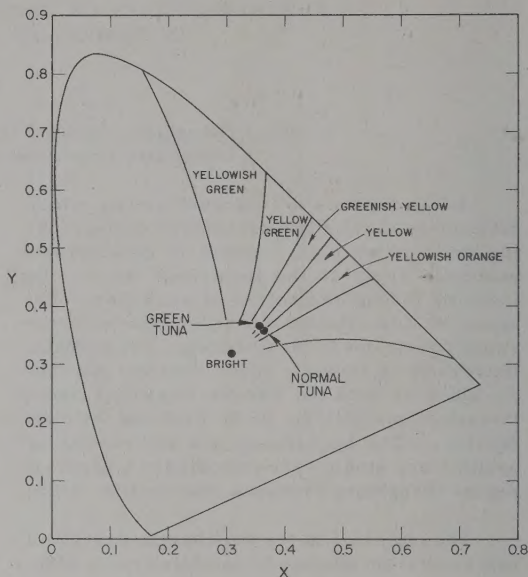


Figure 1.--Chromaticity coordinates for green and normal tuna meat. ICI system.

yellow-green color region. The normal, on the other hand, has more of the orange component present. The reality of the green cast of certain samples seems to be indicated.

Another method used in an attempt to evaluate greenness objectively was to compare absorption in the red and green parts of the spectrum (640 and 540 millimicrons, respectively) for cooked green and normal meat by reflectance measurements. A green sample would be expected to show greater absorption of light in the red end of the spectrum (640 millimicrons) when compared with normal meat. The ratio of the absorbancy at the 540/640 millimicron absorption peaks therefore should be greatest for normal and least for green meat if pigments that absorb in these regions are involved. In addition, we have been conscious throughout this work that pigment content must be a factor affecting the degree or type of alteration that might occur. If we assume that we can use the height of the most characteristic absorption peak for heme pigments (the Soret peak, at about 415 millimicrons) as an indication of the absolute pigment content of the cooked meat and plot this against the above indicated greenness index (540/640 absorption peak ratio) it is possible to observe several significant relationships. Such a plot has been made in figure 2, and it will be noted that normal samples, in general, occupy the portion of the

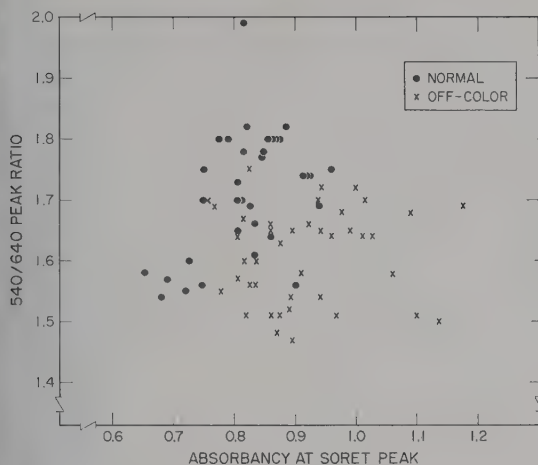


Figure 2.--Variation of the 540/640 millimicron peak ratio with absorbancy at Soret peak (410 - 415 millimicrons), an index of pigment content.

figure indicative of higher 540/640 peak ratio as would be expected, and lower pigment content. It is noteworthy that both the "albacore white" color resulting from low pigment content and the fleshy pink color associated with a high 540/640 peak ratio are accepted as normal by observers, thus emphasizing the complexity of the systems encompassed by the term "normal." Another relationship which can be noted here, namely the association of offcolor with a high pigment content, is completely contrary to the supposition expressed above; that is, that the appearance of greenness is due to a lack of pigment. It should also be noted in passing that the overlapping position of some of the points is due to the uncertainty inherent in the subjective evaluation of precooked flesh.

NATURE OF THE PIGMENTS IN TUNA FLESH

It is obvious that in an investigation of pigment changes it is necessary first to understand the nature of the pigment. It is to be expected, in a muscle system such as tuna flesh, that muscle hemoglobin (myoglobin^{1/}) would be the major pigment present and contribute the largest part of the flesh color. We had assumed this in the investigations herein described, but certain experiments have cast some doubt on the validity of the assumption. It was found by Bowen (1949) and others that the absorption

peaks for mammalian myoglobin were displaced to longer wave lengths in the case of certain derivatives of the pigment. No such shift was observed for fish flesh.

The curves in either transmission or reflection for the systems studied were identical with those that we have measured for hemoglobin and its derivatives. For verification, the solubility of the extracted pigment in buffered phosphate solutions was checked according to the procedure of Morgan (1936), with the incorporation of the modifications of Ginger, Watson, and Schweigert (1954). The absorption curves for the separated pigments are given in figure 3. Assuming that these procedures would give separation of myoglobin from the hemoglobin of tuna flesh through differences in solubility, it was found by measurement of absorption in transmission and reflection that the tuna pigment was about 95 percent hemoglobin. Myoglobin seemed to comprise only a minor fraction of the pigment system. In figure 3 note the residual myoglobin (curve b) in relation to the total pigment content of the extract (curve a). It is felt that these experiments were not exhaustive enough to be conclusive. As far as color changes are concerned, the division of the pigment between myoglobin and hemoglobin is not too pertinent since these changes involve the porphyrin moiety of the pigment molecule which is identical for the two types. For convenience, we shall continue to ascribe the color to myoglobin

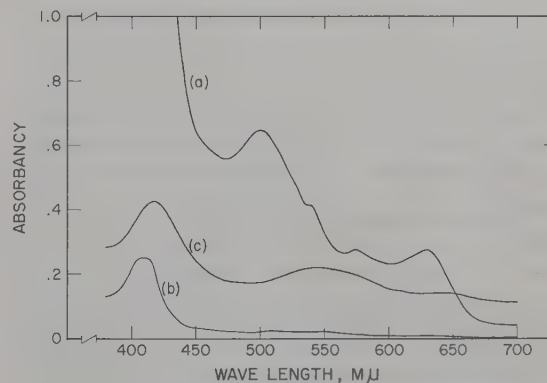


Figure 3.--Separation of aqueous extract of raw tuna (No. 6) into hemoglobin and myoglobin by phosphate fractionation. (a) Transmission curve for original extract. (b) Transmission curve for residual solution after hemoglobin precipitation with phosphate. (c) Reflectance curve of phosphate precipitated material.

^{1/} Myoglobin is similar to hemoglobin except for its lower molecular weight.

until the point has been settled. In this connection, it might be noted that a recent report (Rossi-Fanelli and Antonini 1955) cites work in which myoglobin was separated from tuna flesh giving a compound differing from the corresponding compound found in mammalian flesh. No details of this difference were given.

PIGMENT DERIVATIVES PRESENT IN TUNA FLESH

As has been previously noted (Naughton, Frodyma, and Zeitlin, 1956), extraction of raw flesh gave a colored solution tentatively identified as being largely met- or ferric myoglobin. When reflectance measuring techniques were brought to bear on the problem, it became evident that the raw meat used in these studies contained a mixture of oxy- and metmyoglobin. Examples of the reflectance curves obtained can be seen in figure 4.

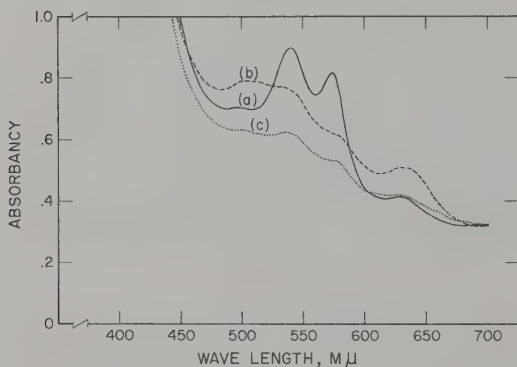


Figure 4.--Reflectance curves showing pigment mixtures found in raw tuna flesh. (a) Largely oxymyoglobin. (b) Largely metmyoglobin. (c) Mixture of met- and oxymyoglobin.

PIGMENT CHANGES IN RAW FLESH

Oxymyoglobin to Metmyoglobin

With the continuation of the measurements on raw meat, it became evident that we were dealing with a pigment system that was extremely changeable and evanescent. It was possible to recognize rather rapid oxidative deterioration in meat even when held under refrigeration. An example involving the change from oxymyoglobin to metmyoglobin can be seen in figure 5. That the change corresponds to an increase in metmyoglobin content can be verified by comparison with the "A" portion of figure 5, which shows

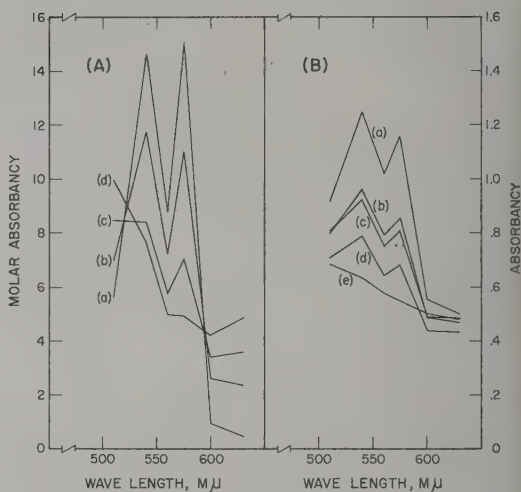


Figure 5.--A. Simplified absorption curve showing increased concentration of methemoglobin in mixtures with oxyhemoglobin increasing from curve (a) to (d). (From Austin and Drabkin 1935-36) B. Similar simplified absorption curves taken in reflection for tuna meat after various periods of freezer storage, showing increased metmyoglobin content. (a) Fresh tuna (sep. sample). (b) After 24 hours' freezer storage. (c) After 36 hours' freezer storage. (d) After 84 hours' freezer storage. (e) After complete conversion to metmyoglobin by chemical oxidation.

in a similar fashion the changes in absorption obtained by Austin and Drabkin (1935-36) for mixtures of oxyhemoglobin and methemoglobin of known content.

Deoxygenation of Oxymyoglobin

An attempt to bring about the reduction of oxymyoglobin to myoglobin by successive evacuation and purging with inert gas (nitrogen)--a technique that works well with oxyhemoglobin in blood--resulted in a more rapid conversion to metmyoglobin (figure 6). This rather surprising behavior may result from the very active form of oxygen released *in situ* in the flesh, which readily oxidizes the ferrous iron in the myoglobin to the ferric form in metmyoglobin. Lemberg and Legge (1949, p. 395) have discussed a similar reaction for hemoglobin in the presence of proton donors. The implications of this reaction in the greening of tuna flesh will be discussed subsequently.

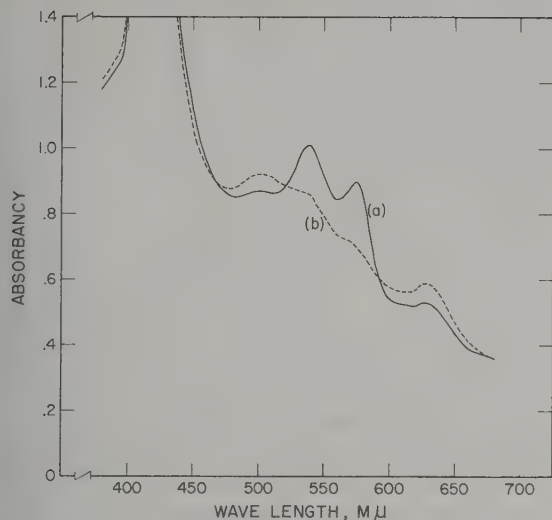


Figure 6.--Oxidation of flesh pigment on treatment with nitrogen. (a) Reflectance curve of fresh tuna flesh. (b) Reflectance curve after alternating evacuation and treatment with nitrogen for 3 hours showing increase in metmyoglobin content.

Pigment Denaturation

Another change that takes place in raw flesh pigments is the denaturation of the protein moiety of the heme pigment molecule. Such denaturation produces so-called denatured globin hemichromes (Lemberg and Legge 1949, p. 228). These are more easily identified from their absorption curves in the reduced condition as the denatured globin hemochromes with pronounced peaks at 528 and 558 millimicrons. Figure 7 shows such spectral reflectance curves obtained with tuna flesh. Strictly fresh meat gave the characteristic single absorption peak of myoglobin in the green region at 555 millimicrons (curve a). Mild intentional denaturation of this meat by heating to 50°C. for short periods (20 minutes in the case illustrated) gave on reduction the appearance of the distinct hemochrome peak at 528 millimicrons (curve b). Similar denaturation can be noted in the absorption curve (curve c) for raw green tuna flesh, and, as would be expected, for cooked green tuna flesh (curve d). It is remarkable that intense commercial cooking in the last instance does not seem to markedly increase the denaturation of the pigment when so judged. There is some indication from a study of a number of such raw reduced samples that the degree of denaturation is related to the amount of

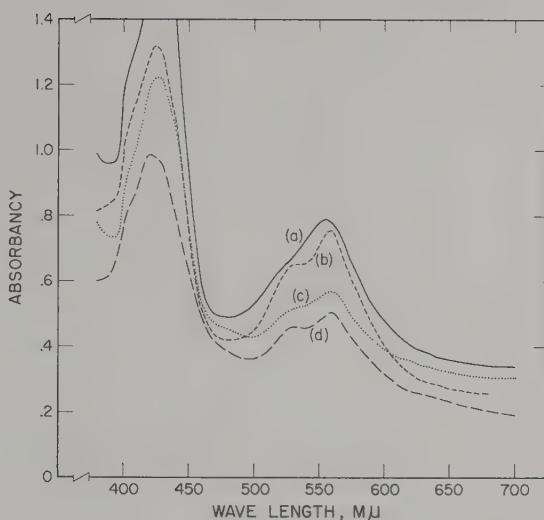


Figure 7.--Reflectance curves showing denaturation by appearance of hemochrome band at 528 mμ after reduction with dithionite. (a) Reduced raw fresh tuna--myoglobin; (b) Tuna flesh of curve (a) after denaturation by heating 20 minutes at 50°C.; (c) Raw green tuna, reduced; (d) Commercially precooked green tuna reduced.

metmyoglobin originally present in the samples and to the greening tendency.

Solubility of Metmyoglobin

Another example of unusual heme pigment changes and behavior noted *in situ* is the unexpectedly greater solubility of metmyoglobin relative to the oxymyoglobin present in tuna flesh. The phenomenon is illustrated in figure 8. It has been noted previously that aqueous extraction of tuna flesh gave absorption curves, measured in transmission, that were characteristic of metmyoglobin. It was always found that such extraction left a pigmented residue whose color showed but slight tendency to decrease with repetition of the extraction. This was initially assumed to be due to the inefficiency of the extraction procedure. Application of spectral reflectance measurements to the problem showed that the metmyoglobin in tuna flesh is characterized by a rather pronounced solubility, while the oxymyoglobin exhibited a high degree of insolubility (compare curves a and b, fig. 8). This suggests the possibility that pigments leaching during thawing and precooking might be a factor in producing a pale condition akin to greening in tuna with a high metmyoglobin

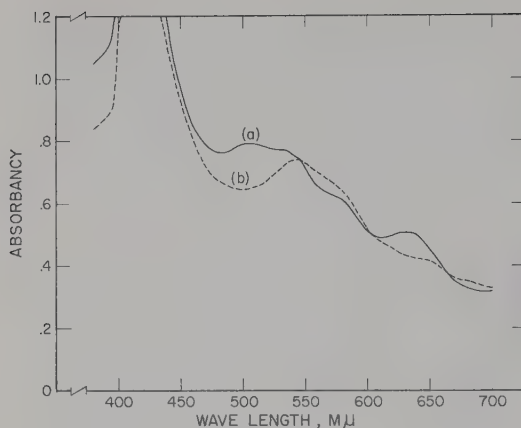


Figure 8.-- Reflectance curves showing solubility of metmyoglobin and insolubility of oxymyoglobin in raw tuna flesh. (a) Raw tuna flesh. (b) Residual flesh after aqueous extraction at pH 6.8. Note disappearance of 500 mμ and 630 mμ metmyoglobin absorption peaks.

content. This effect may be one of the complex of factors related to greening, but it is probably more closely related to a "washed out" condition occasionally observed in tuna flesh.

PIGMENTS IN COOKED TUNA FLESH

The cooking of tuna meat results in the denaturation and coagulation of the proteins present, with consequent lightening of the meat color. Denaturation of the heme protein pigments leads to the formation of the hemochrome (ferrous form), and under oxidative conditions the hemichrome (ferric form) of the denatured globin. Characterizing absorption, aside from the Soret region, occurs at 545 and 575 millimicrons (fig. 8, curves a and b) in agreement with the values listed for the denatured globin hemichrome of hemoglobin (Lemberg and Legge 1949, p. 228). It will be noted by examination of figure 9 that absorption by this substance is rather weak and the peaks are ill defined. A more unique and more easily characterized curve is obtained for the reduced, or ferrous, denatured globin hemochrome, as has been discussed previously. The contrast is evident in figure 9. The color of the reduced hemochrome is pink and more desirable from the consumer's viewpoint. Brown and Tappel (1957) recently have identified this pink compound as being a mixed, denatured, globin nicotinamide hemochrome.

The difference between the spectral reflectance curves of green and normal fish flesh

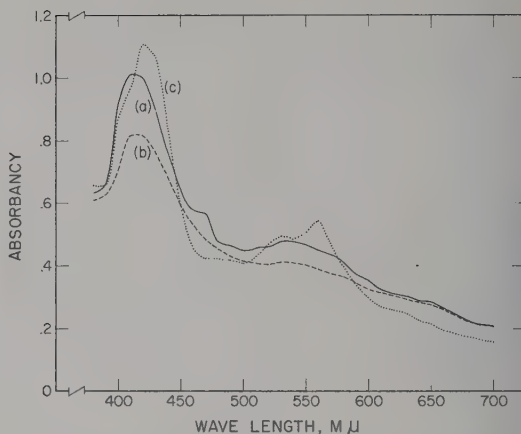


Figure 9.--Reflectance curves showing pigments of cooked tuna flesh. Curves (a) and (b) denatured globin hemichrome of cooked tuna flesh. Curve (c) denatured globin hemochrome of reduced cooked tuna flesh.

seems to lie in the greater absorption by the former in the red region (620 - 660 millimicrons) for a given absorption in the yellow-green region (520 - 580 millimicrons). Thus, in figure 9, curve (b) would be characteristic of flesh with a greener hue than the flesh represented by curve (a).

GREEN PIGMENT IN PRECOOKED FLESH

It proved to be impractical to extract and identify the green component in precooked green flesh, as has been pointed out previously. Another approach would be to cleave the pyrrole ring segment from the protein moiety of the pigment molecule by alcohol--or acetone--hydrochloric acid treatment, and then examine the extract by spectral transmission, and the residue by spectral reflection. Green pigmentation in meat has been attributed to an oxidative attack on the pyrrole ring of the heme pigments, with the resultant production of choleglobin or verdohemochrome (Watts 1954). Removal of the oxidized or disrupted ring by the acid-alcohol or acetone treatment, and spectral examination, would be expected to reveal the nature of the parent pigment. Verdohemochrome, and its postulated precursor choleglobin, would produce biliverdin-like compounds (Lemberg and Legge 1949, p. 458).

The acid-methanol or acetone extracts gave an absorption curve in transmission that showed no characteristic absorption peaks and was very similar to that obtained from the leachate of cooked fish (fig. 10, curve b). Solvent extraction

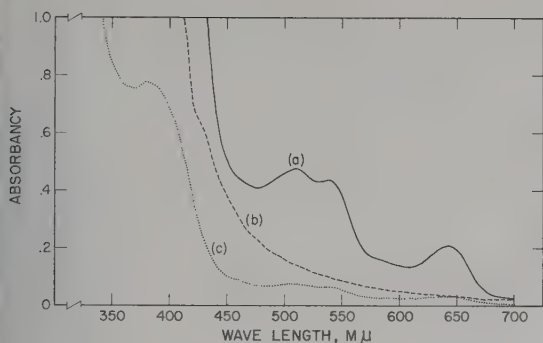


Figure 10.--Spectral absorbance measured in transmission of 1:9, 12 N HCl-methanol extract of precooked green tuna flesh (No. 7). (a) Chloroform extract of HCl-acetone extract. (b) Original HCl-methanol extract. (c) Chloroform extract of (b).

of this material, however, gave an absorption curve in transmission with peaks at 382, 510, 540, and 640 millimicrons (fig. 10, curves a and c). These absorption maxima are compared in table 1 with the peaks reported for some of the products of heme protein disruption that might be identical with the substance found in precooked tuna flesh.

The coincidence of the absorption peaks with those reported by Lewis (1954) for hemin chloride in acetone with excess hydrochloric acid added is particularly striking, and we may conclude that this substance is present in the extract. We should note, however, that we have failed to find the characteristic hemin chloride platelets on microscopic examination of these extracts.

DIRECT EVIDENCE FOR GREEN PIGMENT

The residues left after treatment of the flesh with acid-acetone and acid-methanol were examined by the spectral reflectance technique. The curves obtained were very similar to those reported for acid hematin (Lemberg and Legge 1949, p. 173) and "acid stable hemin" (Lewis 1954). The comparative values are listed in table 2.

Of far greater interest was the slight but definite absorption peak that appeared in the red end of the spectrum. This will be noted in figure 11 at 625 millimicrons for acid-acetone treated meat (curves a, b, and c), and at 610 millimicrons after acid-methanol treatment (curves d and e). The curves show a decrease in this peak height from very green meat (curve a) to less green (curve b) to normal (curve c),

Table 1.--Characteristic absorption peaks of heme pigment derivatives

Pigment		Absorption maxima, millimicrons			
		I	II	III	IV
1	Muscle pigment in chloroform	640	540	510	382
2	Green skeletal pigment of skipjack in chloroform (Fox and Millott 1954)	660	-	-	380
3	Methanolic ester of biliverdin in chloroform (Tixier 1945)	665	-	-	384
4	Biliverdin hydrochloride in HCl-methanol (Lemberg and Legge 1949)	680	-	-	377
5	Protoporphyrin in ether-acetic acid (Lemberg and Legge 1949)	632.5	537	502	395
6	Coproporphyrin in chloroform (Lemberg and Legge 1949)	622.5	533	499	405
7	Hemin chloride and HCl (Lewis 1954)	640	540	512	382

Table 2.--Acid-hematin absorption peaks

Pigment	Absorption maxima, millimicrons			
	I	III	IV	Soret
1 Reflectance of residue in precooked tuna meat after HCl-methanol or HCl-acetone extraction	630	540	500	400
2 Acid hematin (Lemberg and Legge 1949, p. 173) glacial acetic acid	630-635	540	410	400
3 Acid stable hemin (Lewis 1954)	630	-	500	-

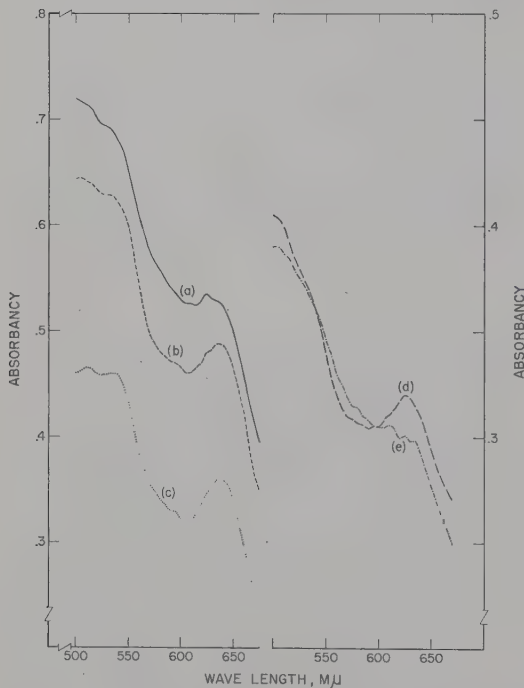


Figure 11.--Reflectance curves of acid-acetone (a, b, c) and acid-methanol (d, e) extracted precooked tuna of decreasing greenness (a, b to c; and e to d). The decrease in absorption with the decrease in greenness in the 610-620 millimicron range is evident.

where the absorption peak has disappeared. A similar effect is noted in the acid-methanol treatment (curve d, normal; curve 3, green meat). It is felt that this peak is direct evidence for the green pigment, the existence of which had

previously been deduced more or less indirectly. A similar pigment, absorbing between 610 and 620 millimicrons, has been reported in both transmission measurements on green-colored extracts and spectral reflectance curves obtained from discolored beef that had been exposed to gamma radiation from a cobalt-60 source (Ginger, Lewis, and Schweigert, 1955). The pigment noted here may be similar, although present in lower concentration and in an insoluble coagulated form. The exact nature of the pigment is still under investigation.

RELATION BETWEEN PIGMENTS OF RAW AND PRECOOKED TUNA FLESH

The examination of many spectral reflectance curves for the flesh of raw tuna reveals the tendency for flesh with a high content of metmyoglobin, characterized by a prominent 630-millimicron absorption peak, to give an offcolor on precooking. Thus, referring to figure 4, one would usually find that raw meat which gave a reflectance curve such as (b) would turn green or gray-green on precooking. The picture is complicated by the presence of oxymyoglobin, which seems to modify the effect of metmyoglobin and, when present in high concentration, produces pink meat that browns rapidly on exposure to air. Frequently a high concentration of both oxymyoglobin and metmyoglobin is found. The oxymyoglobin predominates in effect, and the possible combinations seem to result in a gamut of gray to brown to orange pigmentation depending on the relative amounts of each parent pigment.

An evaluation of the relation of both subjectively and objectively judged color to metmyoglobin content is shown in figures 12 and 13. The height of the absorption peak in the red region at 630 millimicrons, which is characteristic of

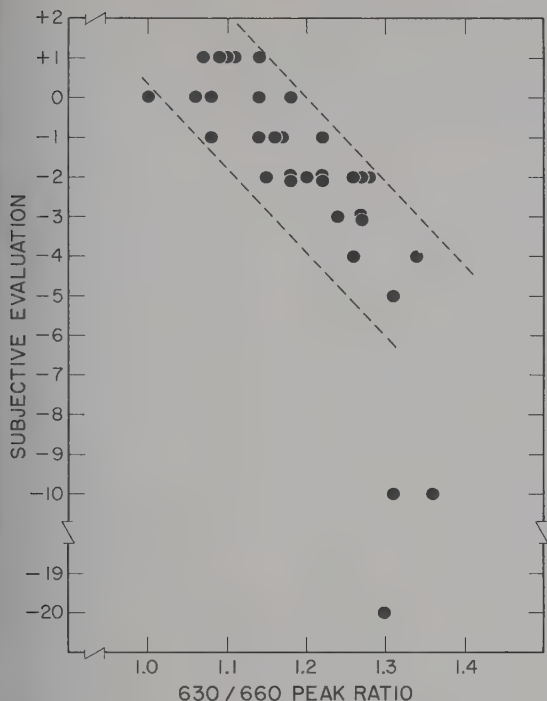


Figure 12.--Relation of metmyoglobin content of raw tuna flesh (as judged by magnitude of spectral reflectance at the 630/660 peak ratio) to the color rating of the same meat on pre-cooking as subjectively judged.

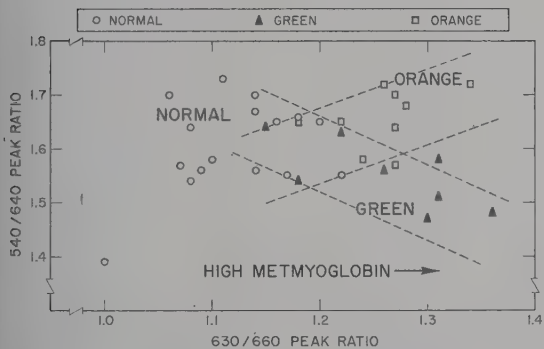


Figure 13.--Relation of metmyoglobin content of raw fish flesh to color as objectively judged (540/640 ratio). Measurements made from absorption in spectral reflectance.

metmyoglobin, was used as an indication of the amount of this pigment in the raw meat and was measured by means of the ratio of 630/660 millimicron absorption. Offcolor of the same meat on pre-cooking was judged subjectively by Mr. Jermann of Hawaiian Tuna Packers on a

plus one (excellent); zero (normal); minus value (for increasing degrees of greenness and off-color) scale. The results are shown in figure 12. There seems to be a definite relation between these factors when judged in this manner.

Objective evaluation of greenness in pre-cooked meat was made through the use of the absorption ratio at 540/640 millimicrons described earlier in this report. The comparison of this color rating with the metmyoglobin content is shown in figure 13. Again we note the indication of an interrelation, complicated by the orange color abnormality that is sometimes noted. It is rather surprising that this also seems to be related to a high metmyoglobin content. The large number of coexisting flesh pigment forms and colors (pink, orange, green, and brown) gives a complicated system in which correlating factors are readily obscured. Nonetheless, the evidence seems to point rather definitely to metmyoglobin as a factor in the discoloration of tuna flesh.

PEROXIDES IN FISH FATS

The suspicion of oxidation as one factor related to greening leads one to speculate on the role of fat peroxides in this phenomenon. The coupled oxidation of hemoglobin and unsaturated fats in mammalian meat tissue has been the subject of much research, summarized by Watts (1954). The oxidation of unsaturated fats to peroxides is accelerated by heme compounds and is accompanied by the oxidation of the heme. The resulting fat peroxide may, in turn, play a role in furthering the deterioration of heme pigments. It is known that hydrogen peroxide forms unstable addition compounds with hemoglobin, which subsequently decomposed with destruction of the heme moiety of the molecule (Keilin and Hartree 1950). We have observed a greening of tuna meat on treatment with dilute solutions of hydrogen peroxide.

To test the possibility of a correlation between peroxide formation and oxidation of the heme pigment, we have determined the fat content flesh by a modification of the cold extraction method of Sperry (1955), carried out in de-aerated solutions under a blanket of nitrogen. The peroxide content was determined by titration of the iodine released from an iodide solution by the peroxide present in the extracted fat with a standard thiosulfate solution. Appropriate blank determinations were made. The results are given in table 3.

For the samples run, there is an indication of a high peroxide content in green and

Table 3. --Fat and peroxide values of raw tuna flesh

Samples	Description	Percent fat	Milliequivs. per 1000 gms. of fat
<u>Green</u>			
No. 1	Green	1.29	40
No. 2	Pale green	0.47	14
No. 3	Slightly green	0.63	24
No. 4	Green	0.82	14
		0.79	12
<u>Very pink</u>			
No. 1	Abnormally pink	0.55	27
No. 2	do.	0.92	20
		1.07	40
No. 3	Orange	0.46	26
		0.44	22
<u>Normal and pale</u>			
No. 1	Normal	0.50	13
No. 2	Washed out	1.57	9
No. 3	Normal	0.59	9
No. 4	do.	0.58	4
No. 5	do.	0.54	10
		0.51	8

offcolor flesh, which is in agreement with the postulated oxidation of fats along with the oxidation causing greening. The increased peroxide is most pronounced for abnormally pink or orange samples, and less so for green.

The investigation of the fat content and the peroxide values, related as they seem to be to the oxidation of heme compounds, is particularly pertinent since it is known that fish derive their fat mainly, if not entirely, from dietary fat. The fat is deposited in the tissues more or less unchanged (Shorland 1956). Therefore it is conceivable that the differences among fish, which result in greenness being exhibited by certain specimens, are related to differences in dietary fat intake. The presence of fats that are susceptible to oxidation (i.e., linoleic and linolenic acid fats) would render heme pigments subject to easy oxidation.

FURTHER INVESTIGATIONS ON LEACHING

It has been noted in previous reports that on precooking, a solution was drained from the fish flesh which was found to exhibit a degree of pigmentation. We have referred to this process as "leaching" and to the product as the "leachate."

Solutions of all leachate pigments gave noncharacterizing absorption curves when

measured in transmission that are identical with curve (b), figure 10. In addition, the residues left on boiling aqueous extracts of raw flesh have the same color and give the same type of absorption curve. As has been indicated previously, extracts of the hemin of precooked meat with acetone or methanol-1N hydrochloric acid (Brückmann and Zondek 1940), gave the same types of absorption curves on measurement in transmission as those resulting from similar treatment of raw meat. In view of this, one would expect to find that heme was the pigmented substance cleaved from the myoglobin in the tuna flesh and leached out during precooking. Repeated efforts, however, to produce the rhomb-shaped crystals of "alpha-hemin" (chlorohemin, hemin), which are so characteristic of this compound when derived from mammalian blood, were not successful (Teichmann test). The identification of this substance is particularly pertinent because of the possible relationship between the phenomenon of leaching and the pronounced solubility of metmyoglobin reported above.

FISH EXHAUSTION AND METMYOGLOBIN CONTENT

As a result of the accelerated conversion of oxy myoglobin to metmyoglobin noted in the absence of oxygen (nitrogen and evacuation), it was hypothesized that a condition of anoxia, or

lack of oxygen, in the muscle of the fish brought on by exhaustion might lead to a high metmyoglobin content with consequent increased incidence of greenening. Such a condition is probable for certain fish caught by the longline method of fishing.

An opportunity to test the theory was afforded through the utilization of the facilities of the Coconut Island Marine Laboratory of the University of Hawaii. A fishing boat was available with a "live-well" in which it was possible to maintain small tuna alive. In addition, small yellowfin tuna abound in local waters in certain seasons. With the cooperation of the staff of the Hawaii Marine Laboratory, it was possible to catch tuna with lures and to kill certain of these within a few minutes of capture while maintaining others in a wounded and dying condition for many hours in the live-well. The latter were finally killed and the flesh of both types was analyzed for metmyoglobin by the reflectance technique. Two sets of such paired samples were obtained. Differences in metmyoglobin content were very slight and seemed to be randomly distributed between the fish killed under the two conditions.

DISCUSSION

Consideration in toto of the experimental work performed in the period covered by this report reveals that it was guided by the assumption, based on evidence gathered in earlier experiments, that there is an actual green pigment that produces the undesirable color in certain samples of precooked tuna. As a working hypothesis, it has been assumed that the green color is due to the pigments that result from the opening of the porphyrin ring of certain of the heme proteins of tuna flesh. This process, which takes place as a result of oxidation, is familiar to food scientists in the meat industry.

A hypothetical picture of the processes occurring in the greenening of precooked meat follows. Certain samples of raw tuna flesh contain a high concentration of metmyoglobin in proportion to the oxymyoglobin content. There is evidence that such tuna are prone to greenness on precooking. The high concentration of metmyoglobin is a result of the decomposition of oxymyoglobin which releases oxygen in an active form capable of oxidizing the ferrous iron of myoglobin, and also capable of producing a denaturation of the protein moiety of the heme protein molecule. This oxidation takes place largely during storage after the death of the fish, and may be catalyzed by the presence of certain fats ingested as a result of peculiarities of the fish diet. The denaturation of the pigment

renders the heme moiety more susceptible to further oxidation, which takes place on precooking, and results in an opening of the porphyrin ring. This last process may result in the production of pigments similar to verdohemochromes, which impart a green color to the meat. Concomitant browning occurs due to the formation of denatured globin hemichromes.

Although this picture is hypothetical, there is some evidence for the steps indicated, and it is offered as a basis for further work.

SUMMARY

Continued work on the green or offcolor condition that appears in the flesh of certain specimens of tuna on precooking has indicated the following:

1. The greenness is an actual color condition, rather than a lack of pigment or offcolor.
 - a. ICI (International Commission on Illumination) color evaluation of the light reflected from green meat shows it to be in the yellow-green region, with somewhat more green color than is present in normal meat.
 - b. Study of spectral reflection shows generally a greater relative absorption of light in the red region of the spectrum for green meat--hence the green color--and indicates a higher concentration of a compound or mixture of compounds absorbing in this region (the green pigments).
 - c. Evidence is offered for a green pigment in precooked meat that has been exposed to hemin cleavage by chemical means.
2. Spectral reflectance studies reveal oxymyoglobin and metmyoglobin as the chief pigments of raw tuna flesh. Mixtures are usually present with a high concentration of oxymyoglobin in the freshest meat, and increasing concentrations of metmyoglobin in older stored meat. Metmyoglobin content increases even on freezer storage.
3. The reactions of the pigments in situ in the raw tuna flesh were studied by reflectance methods and revealed the following:
 - a. Interconversion from oxy- to met- to myoglobin, and reverse were readily achieved by chemical means.
 - b. Metmyoglobin was found to be very soluble in aqueous media while oxymyoglobin was

not easily extracted into the same media.

- c. Oxymyoglobin was converted to metmyoglobin on de-aeration.
- d. Stored meat showed evidence of progressive denaturation of the pigment protein.
4. The characteristics of the pigments of cooked tuna flesh were investigated. One of the pigments, denatured globin hemichrome, was readily reduced to the hemochrome by chemical means.
5. Evidence is presented showing a relation between high metmyoglobin in the raw flesh and a tendency towards discoloration on pre-cooking.
6. Data are cited indicating a low fat peroxide content in normal meat relative to meat inclined to become offcolor on precooking. It is felt that fat oxidation and heme pigment oxidation are interrelated.

The conclusion reached is that greening in tuna flesh is similar to the greening process that occurs in other meats, and is due to an anomalous heme protein oxidation. A hypothetical pathway for the production of the green condition in tuna flesh is outlined.

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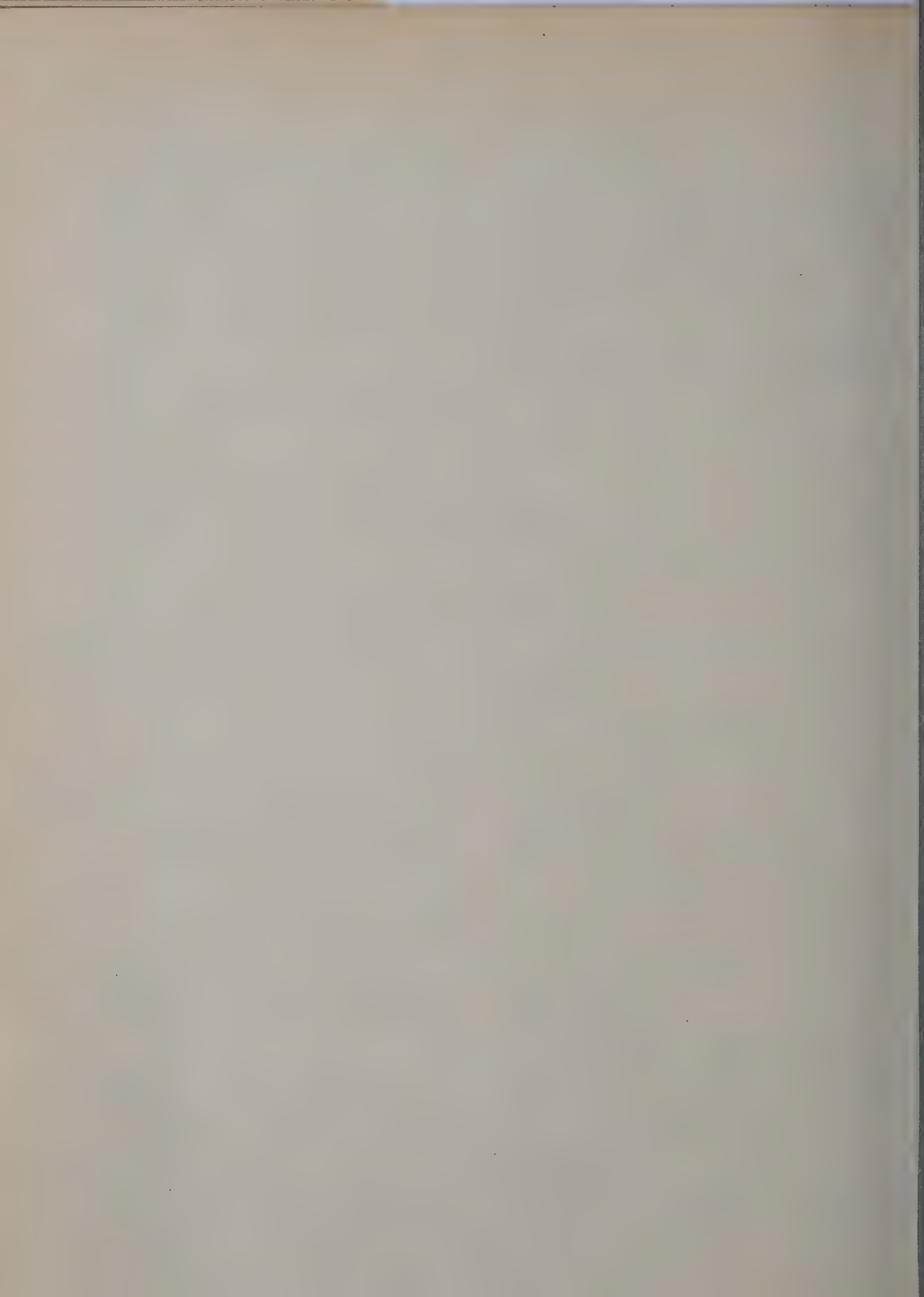
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Spectral Reflectance Applied to the Study of Heme Pigments

It is a common practice to make qualitative and rough quantitative estimates of the content of pigmented substances in materials by the intensity and spectral distribution of color. It is rather surprising, then, that more use has not been made of spectral reflectance in qualitative and quantitative analytic chemistry. It is the intention of this report (1) to point out the potentialities of the method, particularly in biochemical analysis, and to illustrate its application in the investigation of certain heme pigments.

The use of spectral reflectance curves in the specification of color by the physicist is well known. Lermond and Rogers (2) have recently pointed out the possible wider utility of spectral reflectance measurements in chemical analysis and have reviewed the limited amount of work in this field. Applications in biochemistry seem to be particularly rare.

In the course of research on pigment systems in fish flesh, we investigated the use of spectral reflection measurements. A standard reflection attachment to the Beckman DU spectrophotometer was used. Samples, either 90-mesh, nonabsorbing powders with absorbing solutions or solids added, or tissue forced through a 16-mesh, stainless-steel screen, were packed into 1/4 by 1/16-in. aluminum planchets and covered with glass plates. Comparison was made with a standard consisting of the nonabsorbing diluent powder or with a disk of high-fired alumina.

Adherence to Beer's law was tested by adding different amounts of standard copper sulfate solution to the crystalline alumina diluent and measuring the absorbancy at 620-m μ wavelength. The law seems to be applicable at this wavelength and for the range of concentrations indicated (Fig. 1). These results are at variance with those that Winslow and Liebhafsky (3) reported for reflectance from known concentrations of metals spot-tested on paper. The discrepancy may be due to the difference in the thickness of the supporting media for the samples used in the two experimental situations. Measurements were attempted with whole blood dispersed on 90-mesh crystalline alumina. In this case, adherence to Beer's law was found at low concentrations, but oxidative changes caused deviation in the higher range.

In transparent, internally absorbing

systems (dielectrics), it can be assumed that reflection takes place at phase interfaces and by diffuse scattering from large molecules. Adherence to Beer's law would signify that, for systems of similar opacity, the average path length of the incident and emergent beam is the same and would also justify the use of absorbancy (optical density) in the plotting of spectral reflectance data. Thus spectral reflectance can presumably be used for the comparative quantitative analysis of stable systems of dielectric materials of similar general composition. Such measurements have been applied in the present work.

The use of the method for the characterization of pigments by their reflectance curves is illustrated in Fig. 2. Various derivatives of respiratory pigments can be identified in the reflection spectra of tuna flesh that is exposed to a variety of oxidative environments. An advantage afforded by this technique is the possibility of evaluating the spectral absorbance of opaque concentrated systems without recourse to the special cells, or to dilution in solution with its attendant possibility of alterations, that are employed in transmission methods. For example, the spectrum of whole human blood can be directly determined using an inert crystalline alumina diluent (Fig. 2c).

Spectral reflectance is particularly suited to *in situ* studies on pigment systems where extractive procedures are difficult or impossible or where such procedures would cause undesirable changes. It is characteristically a simple technique in that a minimum of preparative and extractive operations is involved. Specifically, absorbance studies on coagulated

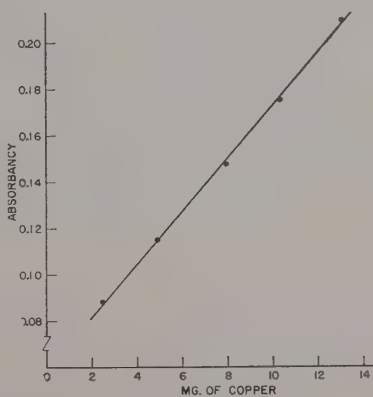


Fig. 1. Beer's law plot for copper on 90-mesh crystalline alumina.

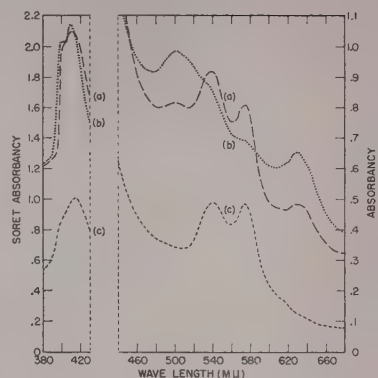


Fig. 2. Spectral reflectance curves *a*, mixed oxymyoglobin and metmyoglobin in tuna flesh; *b*, metmyoglobin in tuna flesh; *c*, oxyhemoglobin in whole blood.

proteins were possible; in addition, the examination of residues after the extraction of certain components gave a more complete picture of extraction efficiency and relative solubilities. Furthermore, one is able to follow the course of induced or natural chemical reactions in such systems. For the heme protein systems studied, the wavelengths of absorption maxima in reflection corresponded exactly to those found in transmission, and complete interchangeability of data was noted. Thus the large amount of data accrued from measurements in transmission would be available to workers in the field of reflectance in systems where this interrelationship is found to be true.

The measurement of spectral reflectance offers a method for the study of dielectric materials that absorb and reflect internally, as opposed to surface reflectors such as metals. It is felt that this investigative tool merits the further attention of the biological and analytic worker.

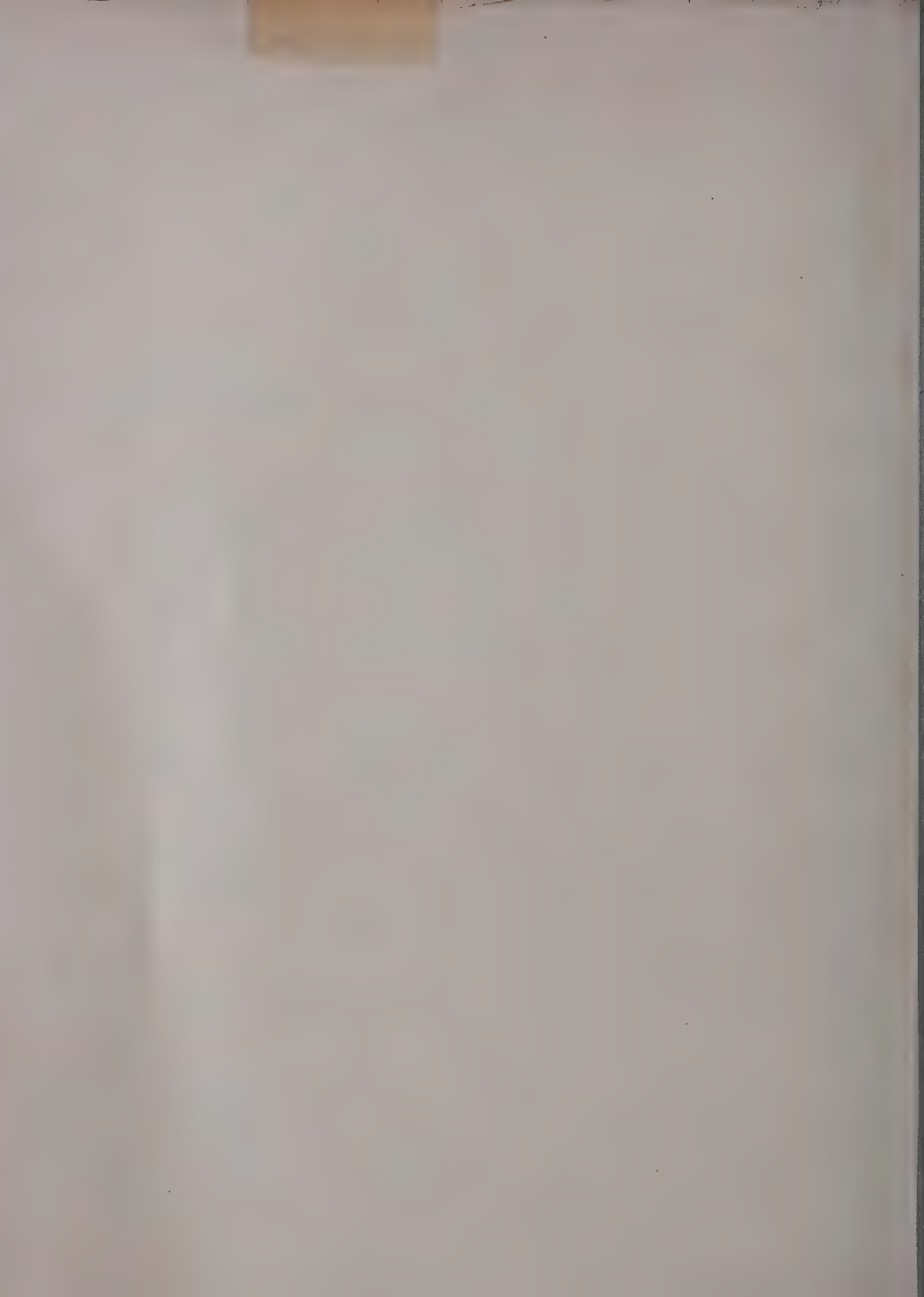
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References and Notes

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DEVELOPMENT OF "HONEYCOMBING" IN HAWAIIAN SKIPJACK TUNA

By Tamio Otsu*

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BACKGROUND

The skipjack tuna (*Katsuwonus pelamis*) supports the most important fishery in the Hawaiian Islands--landings amount to about 10 million pounds annually. It is abundant during the summer months (May-September), when more than 75 percent of the annual catch is made. Besides the usual problems besetting any fish-

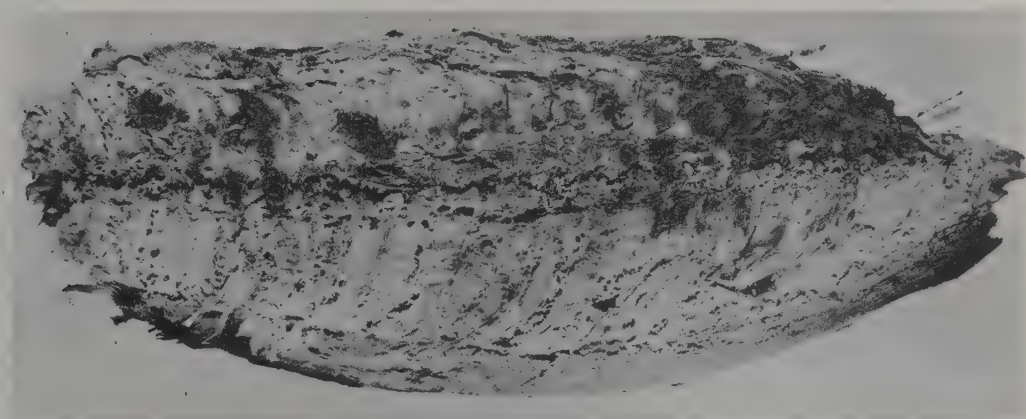


Fig. 1 - An extensively honeycombed skipjack tuna fillet after precooking.

ery, the industry is troubled from time to time with honeycombing, a pitted and cellular condition which appears in some of the fish during precooking, making the meat unsuitable for canning. During 1956 about 58,000 pounds of skipjack were so affected.

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Incidental to studies on skipjack distribution and abundance, the Service's Pacific Oceanic Fishery Investigations conducted several experiments to ascertain whether degree of sexual maturity, size of fish, or type and intensity of refrigeration were related to the appearance of honeycombing during precooking. These experiments suggest that honeycombing is independent of sexual maturity or fish size, but clearly show that it can be induced by holding the fish without refrigeration. Further, they suggest that slight variations in the holding temperature have a striking effect on the length of time required to induce honeycombing, small increases in temperature greatly accelerating the development of the condition. This is believed to be the key to the pronounced seasonality of the problem in Hawaii, where it is significant only during the summer months.

DESCRIPTION OF HONEYCOMBING

The term "honeycombing" is applied to the meat of cooked fish which is pitted and cellular in appearance. Figures 1 and 2 show an extreme case of this condition as it appears after precooking at the cannery. For comparison, the appearance

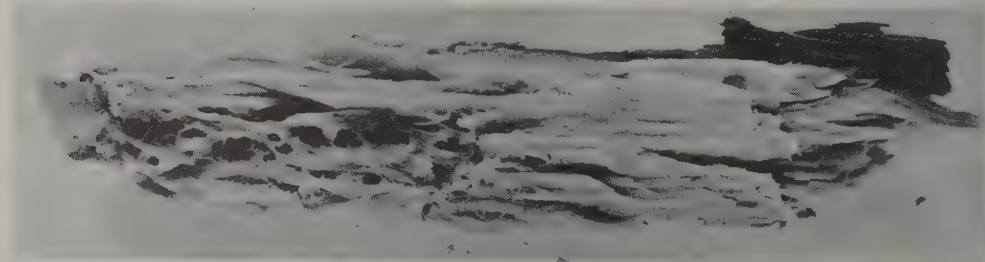


Fig. 2 - A closeup of a piece of honeycombed meat taken from the fish shown in figure 1.

of a normal, nonhoneycombed fish after precooking is shown in figure 3. There are various degrees of honeycombing; in some cases a slight trace may appear in the region of the nape, while in others the condition may be found throughout the entire

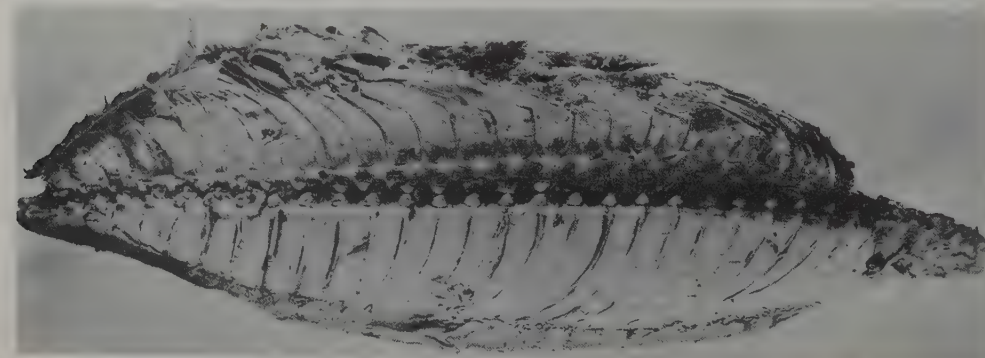


Fig. 3 - A normal nonhoneycombed skipjack tuna fillet after precooking.

body. During the course of the experiments discussed in this paper, it was observed that honeycombing starts at the nape and works posteriorly towards the caudal region. There were also some indications that it begins in the interior of the fish near the backbone and progresses outward.

Honeycombing should not be confused with another condition in the fish in which the meat has a texture variously described as "putty," "mushy," or "jellied." The latter condition is probably caused by sporozoan infection of the muscles as described for yellowfin tuna meat by Arai and Matsumoto (1953).

SEXUAL MATURITY

PROCEDURE: In order to study the relationship between honeycombing and sexual condition of the fish, 131 female skipjack were examined from a load of fish butchered and precooked on August 11, 1954. Ovaries were collected to determine the degree of ova maturity. When the fish were canned on August 12, they were examined for evidence of honeycombing.

RESULTS AND DISCUSSION: Of the 131 fish, ranging in weight from 14 to 18 pounds, 7 (5.3 percent) were honeycombed. The degree of maturity of these 7 as well as of 19 nor-

Table 1 - Results of Ova Measurements Made to Determine Degree of Sexual Maturity of Normal and Honeycombed Female Skipjack Tuna

Honeycombed Fish		Normal Fish	
Fish Size (Dressed Weight)	Mean Ova Size	Fish Size (Dressed Weight)	Mean Ova Size
Lbs.	mm.	Lbs.	mm.
14	.587	-	.572
14 $\frac{1}{4}$	.590	-	.585
15 $\frac{1}{2}$	.574	14	.605
16	.565	14 $\frac{1}{4}$	.572
16	.594	15	.561
16 $\frac{1}{2}$	.574	15	.596
15 $\frac{1}{2}$	.608	15	.563
15.5	.585	15 $\frac{1}{2}$	.592
		16	.601
		16	.598
		16 $\frac{1}{2}$	.594
		16 $\frac{1}{2}$	.579
		16 $\frac{1}{2}$	.594
		17	.598
		17	.609
		17	.607
		17	.576
		17 $\frac{1}{2}$	.607
		17 $\frac{1}{2}$	.618
		Mean	16.1
			.591

mal fish was estimated by measuring 10 eggs of the largest group in the ovaries (table 1). The mean size of the largest group of eggs in the ovaries was about the same for all ovaries examined. Furthermore, no gross differences were detected between the ovaries of honeycombed and normal fish; all appeared to be in the same stage of maturity. Hence, this experiment indicated no relationship between honeycombing and the sexual state of the fish.

REFRIGERATION

Experiments designed to test the effect of refrigeration followed this general pattern: (1) a group of skipjack were taken from a school by live-bait fishing; (2) a portion of the group were frozen within an hour or two as controls; (3) the remainder received various experimental treatments prior to freezing.

EXPERIMENT NO. 1--Crushed Ice vs. Freezing: On July 25, 1954, 66 skipjack (16 to 24 pounds) were taken from a school 60 miles off the southwest coast of the island of Hawaii: 26 were dry frozen within an hour of capture; 1 $\frac{1}{2}$ hours later the remaining 40 were packed in crushed ice in an unrefrigerated brine well.

The iced fish were repacked the next day, since the ice melted rapidly and many of the fish on the bottom were immersed in water. In order to control this excessive melting, partial refrigeration was resorted to on the morning of July 27,

approximately 45 hours after the start of the experiment. The brine tank temperature was lowered to 40° F. in order to reduce the rate of melting and was occasionally lowered further to 20° F. in order to refreeze the melted ice. Unfortunately, this resulted in freezing the fish, so this experiment in essence tests immediate freezing against 45 hours in crushed ice.

More fish were added to the freezer from another school fished on July 28, bringing the total of dry-frozen fish to 40. These were almost the same size as the first group (15-24 pounds).

The 80 skipjack (40 dry-frozen and 40 "iced") were delivered to the cannery on August 1, a week after the beginning of the experiment. The two groups of fish were butchered and precooked on August 2 in two separate cartloads. They were examined and packed on August 3.

Results and Discussion: All except two fish were in excellent condition. These two, both from the "iced" group, were rejected, one for a very slight trace of probable honeycombing near the nape and the other for a slightly "mushy" texture. The defects in both cases were detected only after the most critical examination.

This experiment indicates no significant difference in the condition of fish frozen immediately after capture and those held in crushed ice for a period of 45 hours prior to freezing.

EXPERIMENT NO. 2--Freezing vs. Holding at Sea-Water Temperature: On August 16, 1954, 80 skipjack (15-32 pounds) were taken 20 miles north of the island of Molokai: 40, selected at random, were frozen within 1½ hours of capture; the remaining 40 fish were held in unrefrigerated circulating sea water for 14 hours (15 hours from capture) before they were frozen. The sea-water temperature during this period ranged between 78.0° F. and 79.0° F. and averaged 78.4° F. This is the type of storage generally used by commercial fishermen in Hawaii for cannery deliveries. The length of time fish are held in sea water prior to delivery at the cannery, where they are held in brine at 32° F., depends on the location of the catch and other operational factors.

Table 2 - Results of Experiment Testing the Condition After Precooking of Fish Frozen Shortly After Capture and Fish Held in Sea Water for 14 Hours Before Freezing

	Dry Frozen Immediately			Held in Sea Water 14 Hours 1/		
	Number Rejected 2/	Number Accepted	Total 3/	Number Rejected 2/	Number Accepted	Total 3/
Males	0	18	18	20	3	23
Females	1	19	20	14	1	15
Total	1	37	38	34	4	38

1/ These fish were on deck for 1 hour before being stowed. Temperature of sea water ranged from 78.0° F. to 79.02° F., averaging 78.4° F. during the experiment.

2/ Rejected because of honeycombing.

3/ Only 38 of the 40 fish in each lot were followed through the cannery. Identification tags were lost on the remaining 4 fish.

Just prior to freezing, the unrefrigerated fish were somewhat soft, but none emitted any "off" odor nor showed noticeable signs of decomposition. The two groups of fish (40 dry-frozen and 40 held in sea water) were delivered to the cannery on August 30, 1954, and were butchered and precooked on August 31 and canned on September 1.

Results and Discussion: Of the 38 frozen fish followed through the cannery, only 1 (2.6 percent) was found to be honeycombed; of 38 that had been held in sea water, 34 (89.5 percent) were honeycombed (table 2). Size and sex distributions of the two groups were similar (tables 2 and 3). The stomachs of both groups

were generally well filled, and many contained partly digested young skipjack, suggesting that their immediate precapture histories were essentially identical.

This experiment coincided with the peak of the skipjack season, and at the time honeycombing was quite common in the commercial catch, which is held in sea

Table 3 - Size of Fish in the Experiment Testing the Condition After Precooking of Fish Frozen Shortly After Capture and Fish Held in Sea Water for 14 Hours Before Freezing

	Size Groups (cm.) ^{1/}					Not Recorded	Total
	67-70	71-74	75-78	79-82	83-84		
Fish frozen...	5	27	3	2	0	1	38
Fish held in sea water...	9	14	9	5	1	0	38

^{1/} The fish ranged in size from 67 to 84 cm. in total length or approximately 15 to 32 pounds each in weight.

water from the time of capture until delivery at the cannery. The results of this single experiment did not in themselves answer the question of whether or not the skipjack are at this season somehow inherently more susceptible to honeycombing than at other times. They did, however, strongly suggest that the phenomenon could, at this season, be produced to a high degree in one batch of fish and almost completely prevented in another batch of similar fish simply by regulating the temperature at which the fish were held after capture.

EXPERIMENT NO. 3--Varying Time in Sea Water vs. Immediate Freezing:

On May 25, 1955, 82 skipjack averaging 7 pounds and ranging from about 5 to 11 pounds in weight were taken a few miles off Oahu. The control group of 32 fish selected at random was frozen within 1 hour after capture. The remaining 50 fish were put in unrefrigerated circulating sea water, and at 5-hour intervals groups of 10 fish were transferred from the sea water to the freezer, the last group being transferred after 25 hours in sea water (26 hours from time of capture). The temperature of the sea water during the 25 hours ranged between 74.7° F. and 75.6° F. and averaged 75.3° F. On May 28, 1955, the 82 experimental fish were delivered frozen and held frozen until June 8 when they were air-thawed; they were precooked on June 9, and examined on June 10.

Results and Discussion: The results (table 4) were in general consistent with those obtained in experiment No. 2. The control group of 32 fish was completely

Table 4 - Results of Experiment No. 3

Group	Number of Fish	Hours in Sea Water ^{1/}	Cannery Results		Remarks ^{2/}
			Number Honeycombed	Percentage Honeycombed	
A	32	0	0	0.0	Completely acceptable
B	10	5	0	0.0	Do.
C	10	10	0	0.0	Do.
D	10	15	0	0.0	Do.
E	10	20	10	100.0	Degree of honeycombing about 80 percent in each fish
F	10	25	10	100.0	Degree of honeycombing about 95 percent in each fish

^{1/} All fish were on deck for 1 hour before being stowed. Sea-water temperature, 74.7° F. - 75.6° F., averaging 75.3° F.

^{2/} Observations by a cannery representative.

acceptable with no trace of honeycombing, but the experimental groups gave varying results. There was no honeycombing in those held from 5 to 15 hours (6-16 hours from capture) in sea water, but the 20- and 25-hour groups (21-26 hours from capture) were all honeycombed. In the previous experiment fish held in seawater for 14 hours developed honeycombing, while in this instance the 15-hour group did not. The significant differences between the two experiments were: (1) the first experiment was conducted in August and the second in May; (2) the sea-water temperature averaged 78.4°F . in August and 75.3°F . in May; (3) the fish used were smaller in May; (4) the fleet was experiencing honeycombing in August but not in May. In view of these differences, the results appear to indicate that honeycombing is a seasonal phenomenon only in that it is related to seasonal changes in the sea-water temperature, and that it can probably be produced in Hawaiian skipjack at any season if the fish are kept at high enough temperatures for a long enough time.

EXPERIMENT NO. 4--Varying Time in Sea Water vs. Immediate Freezing:

Following the same design as in the previous experiment, this trial used 90 fish averaging 28 pounds (25 to 34 pounds) each taken a few miles off the northwest coast of Oahu on June 9, 1955: 40 fish (Group A) were placed in the freezer within $1\frac{1}{2}$ hours of capture; the remaining 50 fish were held in circulating sea water for varying lengths of time up to 25 hours (27 hours from capture). The sea-water temperature during the 25-hour interval ranged between 75.0°F . and 76.5°F ., averaging 75.8°F .

The following observations were made at the time of transfer of fish from sea water to the freezer.

Group	Hours In Sea Water	Remarks
B	10	Fish with slight off-odor but quite firm
C	15	Do.
D	20	Fish with ripe odor; meat somewhat softer
E	25	Fish with ripe odor; soft meat; deteriorating

Unfortunately, as the ship's freezer was overcrowded, the fish did not freeze properly, and when they were delivered to the cannery's freezer on June 10, 28 hours after the start of the experiment, only a few of the control group were completely frozen. On June 14 the fish were removed from the cannery freezer to

thaw. It was found at this time that four fish had lost their tags. These fish had been tied together in pairs with a single label, and since two groups of 10 were exactly two short, it was known that the four unlabeled fish had come from only two groups. By comparing the general condition of the two pairs of unidentified fish with the two groups, it was possible to make probable assignments. Pair X was in condition comparable to the remaining 8 fish of group C, and pair Y to group D (see table 5).

Results and Discussion:

There was a definite progression in the degree of honeycombing with the length of time the fish were kept in sea water (table 5).

Table 5 - Results of Experiment No. 4					
Group	Number of Fish	Hours in Sea Water ^{1/}	Cannery Results		Remarks ^{2/}
			Number Honeycombed	Percentage Honeycombed	
A	40	0	0	0.0	One fish with a "putty" texture
B	10	5	1	10.0	One fish with "very faint trace of what could be the start of honeycombing"
C (X)	8 2 (?)	10 10 (?)	1 1	20.0	Two fish with "slight trace of what could be start of honeycombing" at nape--only at the surface
D (Y)	8 2 (?)	15 15 (?)	8 2	100.0	All honeycombed; degree of honeycombing 5, 10, 10, 10, 20, 20, 20, 20, and 50 percent, all at nape
E	10	20	10	100.0	All honeycombed; degree of honeycombing 20, 20, 20, 20, 25, 40, 40, 45, 45, and 80 percent. All at anterior portion of body, none in caudal region
F	10	25	10	100.0	All honeycombed; degree of honeycombing 10, 20, 40, 50, 55, 55, 80, 80, and 90 percent. Only caudal region unaffected

^{1/} All fish were on deck for 2 hours before being stowed. Sea-water temperature, 75.0°F .- 76.5°F ., averaging 75.8°F .

^{2/} Observations by a cannery representative.

(?) indicates probable assignment of fish in the group as discussed in text.

Generally, the fish held in sea water for 15 hours or more were badly honeycombed; however, there were a few fish in the other groups which had possible traces of the condition. It may be relevant to reiterate here that in this experiment the fish

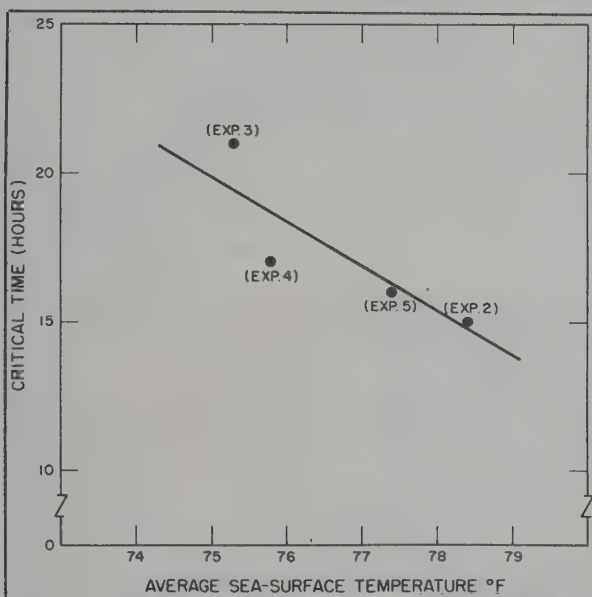


Fig. 4 - The relationship between average sea-water temperature and the length of time fish were held before honeycombing developed. (The sea-water temperature is the average surface temperature for the period in which the fish were held in sea water. Temperatures were obtained from bucket thermometer and thermograph readings. The "critical time," which is the time required to induce honeycombing in 90 percent of the fish, includes the time the fish were on deck prior to treatment.

Note: The critical time was not definitely established in experiment No. 2 since only one group of fish was held in sea water.)

bring well containing the fish ranged between 76.2° F. and 80.0° F., averaging 77.4° F. The 80 fish were delivered to the cannery's freezer on August 26, 1955, precooked on August 31, and examined on September 1.

Results and Discussion: The results (table 6) were essentially similar to those obtained in the previous experiments. Some honeycombing was evident in fish kept unrefrigerated for 13 hours, but the bulk of the honeycombing occurred in groups left unrefrigerated for 16 hours or longer. Here again the results clearly indicated a progression in the degree of honeycombing with the length of time the fish were held in unrefrigerated sea water.

SUMMARY

The results of these experiments are remarkably consistent in showing that honeycombing develops in Hawaiian skipjack held without refrigeration, independent of sexual maturity or size of the fish. The seasonality of occurrence observed in the commercial landings (the condition is usually noticed during the summer) is not at all apparent in the experimental results, as honeycombing resulted from delayed refrigeration in experiments performed at different times of the year. It appears that the rate of honeycombing is more rapid at higher sea-water temperatures (fig. 4), and since the months of highest water temperatures in Hawaii coincide with the peak

did not freeze properly until they had been transferred to the cannery's freezer, 28 hours after the start of the experiment. This may have been the reason for the development of some honeycombing in the groups refrigerated after only 5 and 10 hours in sea water.

This experiment, both in terms of results and design, closely resembled the preceding test, except that the fish were larger (28 pounds versus 7 pounds) and the sea water was slightly warmer. At the time of the experiment (June) the commercial fleet was not experiencing honeycombing.

EXPERIMENT NO. 5--Varying Time in Sea Water vs. Immediate Freezing: The final experiment in the series was conducted on 80 skipjack taken 19 miles off the west coast of Hawaii on August 17, 1955. These fish averaged 4½ pounds in weight and ranged from about 3½ to 5 pounds. The control group of 10 fish was frozen within 1 hour of capture and the remaining 70 were held in circulating sea water for lengths of time varying from 6 to 24 hours (7 to 25 hours from capture) and then frozen.

The sea-water temperature in the

skipjack season and peak "honeycombing season," it may be inferred that there is a close relationship between water temperature and honeycombing.

The relative fishing success during the peak skipjack season may also affect the onset of honeycombing. Generally, more fish can be taken from a single school during the peak than during the off-season. This may mean that larger numbers of fish are put into the bait well at one time, possibly causing an appreciable rise in the temperature of the sea water, because the body temperature of skipjack immediately after capture is generally higher than the water temperature (Uda 1941). Furthermore, it is believed that the skipjack undergoes an initial increase in temperature for several hours after landing, similar to that reported for the albacore (Scagel 1949). If, under these circumstances, the circulation in the bait well were impeded by a large quantity of fish, it would take considerable time for the temperature of the water in the well to revert to the normal sea-water temperature, and thus the tendency for honeycombing to develop in the warm summer sea water would be aggravated.

Group	Number of Fish	Sea Water ^{1/}	Cannery Results		Remarks ^{2/}
			Number Honeycombed	Percentage Honeycombed	
A	10	0	0	0.0	All in good condition
B	10	5	0	0.0	Do.
C	10	9	0	0.0	Do.
D	10	12	3	30.0	Slight traces on these three fish
E	10	15	9	90.0	Slight to minor on these fish - all at the nape
F	10	18	10	100.0	All honeycombed; degree of honeycombing 20-75 percent
G	10	21	10	100.0	All honeycombed; degree of honeycombing 95-100 percent
H	10	24	10	100.0	All honeycombed; degree of honeycombing 100 percent in each fish

^{1/} All fish were on deck 1 hour before being stowed. Sea-water temperature, 76.2° F., 80.0° F., averaging 77.4° F.

^{2/} Observations by a cannery representative.

Although it has been shown that there is a relationship between lag in refrigeration and honeycombing, the basic cause of the condition has not been determined. Further experiments are necessary before precise methods of eliminating or reducing the condition can be prescribed. The results of these few experiments, however, do suggest that in Hawaii a modest amount of refrigeration on the boats would postpone the development of honeycombing long enough to permit delivery of the fish in good condition to the canneries' chill tanks. It might suffice to handle the catch in crushed ice, or simply to add a little ice to the sea water in which the fish are held aboard the boats.

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ANOTHER RECORD OF THE RARE SHARK, *EUPROTOMICRUS BISPINATUS*, FROM THE PACIFIC OCEAN.—On April 3, 1956, at a night-light station occupied by the research vessel CHARLES H. GILBERT of the Pacific Oceanic Fishery Investigations, a female specimen of an unusual pelagic shark, *Euprotomicrus bispinatus* (Quoy and Gaimard), 242 mm. in total length, was dipnetted by the authors. The position of capture was 32°46'N., 176°42'W., approximately 260 miles north of Midway Islands. The EDO

fathometer indicated the depth of the ocean in that region to be about 2,600 fathoms, and the surface temperature was 62.5°F. When first seen, the shark was cruising slowly on the surface which was illuminated by the deck lights of the ship.

Recent descriptions of this rare and peculiar shark are given by Hubbs and McHugh (1951, Calif. Acad. Sci., Proc. IV, 27(6) : 159-76) and also King and Ikehara (1956, Pacific Science, 10(1) : 17-24).—TAMIO OTSU AND HOWARD O. YOSHIDA, U. S. Fish and Wildlife Service, Honolulu, Hawaii.

OBSERVATIONS ON THE SPEARFISHES OF THE CENTRAL PACIFIC

BY WILLIAM F. ROYCE

FISHERY BULLETIN 124

From Fishery Bulletin of the Fish and Wildlife Service

VOLUME 57

**UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE**



UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*
FISH AND WILDLIFE SERVICE, Arnie Jo Suomela, *Commissioner*

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ABSTRACT

The taxonomy, distribution, size, food, and spawning habits of spearfishes are considered. Observations on several hundred spearfishes caught in the central equatorial Pacific and in the Hawaiian fishery are presented, together with an extensive review of Japanese and other literature. A morphometric study shows marked variation in all diagnostic characters and allometric growth in many.

Six species are recognized: swordfish (*Xiphias gladius*), shortnose spearfish (*Tetrapturus angustirostris*), sailfish (*Istiophorus orientalis*), black marlin (*Istiompax marlina*), striped marlin (*Makaira audax*), and Pacific blue marlin (*Makaira ampla*).

All six species are shown to be fishes of the high seas of wide distribution in the Pacific, but with different centers of abundance. The swordfish and striped marlin prefer the more temperate waters, the Pacific blue marlin the equatorial region, and the black marlin the coastal areas off Asia, America, and Australia. Maximum known weights of the Pacific forms (in pounds) are as follows: Swordfish—1,061, shortnose spearfish—114, sailfish—132, black marlin—1,560, striped marlin—483, and Pacific blue marlin—1,450. All are broadly carnivorous on fish and cephalopods. The Pacific blue marlin probably spawns throughout most of the year in equatorial waters.

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OBSERVATIONS ON THE SPEARFISHES OF THE CENTRAL PACIFIC

By WILLIAM F. ROYCE, *Fishery Research Biologist*

Since 1950 the Pacific Oceanic Fishery Investigations (POFI), U. S. Fish and Wildlife Service, has been investigating the high-seas fishery resources of the tropical and subtropical Pacific Ocean. These investigations have shown that several kinds of tunas, particularly, yellowfin (*Neothunnus macropterus*), skipjack (*Katsuwonus pelamis*), and albacore (*Germo alalunga*), form the most promising fishery resources in this area.¹ Moreover, these tunas are commonly found associated with two other groups of large fishes, the spearfishes, principally the marlins, and certain species of sharks. An understanding of the role of both of the latter groups is important because they compete with the tunas for food, but the marlins, in particular, are objects of great interest in themselves because of their value for sport along the coast of the Americas and for food along the coast of Asia.

Despite the interest in and value of the marlins, these spectacular fish are little known to Americans. Their habits, their wide distribution on the high seas, even the number of their species, have not been known. Much information has appeared in Japanese literature during the last two decades, but little has been written in English, and even if it had been, the uncertainty about the species occurring on both sides of the Pacific might have prevented associating the species of the western Pacific with those found off the Americas.

The spearfish problems discussed in this paper include (1) a study of diagnostic characters and morphological comparisons of the species, (2) a decision as to the correct names, and (3) observations on distribution, abundance, and habits. For the latter we shall use our observations and refer extensively to the Japanese literature. We shall not attempt a monograph, however. Observations on the spearfishes in all parts of the world are

being added to the literature so rapidly and so little is known that such a treatment would be premature.

Most of our data have been obtained from spearfishes caught on longline fishing gear from POFI vessels. This gear has been described by Niska (1953) but, briefly, it consists of a series of baited hooks 15 to 30 fathoms apart suspended from a line at depths of about 200 to 400 feet. On all cruises made after July 1952 (table 1) records were kept of the species of spearfishes caught at each station (fig. 1), and in many instances morphometric measurements were made, together with observations on sex, sexual condition, and food in the stomach. Such observations were not as complete as might be desired because the primary assignment on each cruise was to obtain information on the tunas, and observations on the spearfishes were made as time permitted.

TABLE 1.—The longline fishing cruises of POFI vessels on which spearfish data have been collected, 1952-54

Vessel and cruise	Cruise period	Locality and west longitude
<i>John R. Manning:</i>		
No. 12.....	8/16-9/15/52.....	Equatorial area. 140° and 150°.
No. 13.....	10/16-12/6/52.....	Equatorial area. 150° and 170°.
No. 14.....	1/22-3/25/53.....	Equatorial area. 140° and 150°.
No. 15.....	4/28-6/16/53.....	Equatorial area. 150° and 170°.
No. 16.....	7/24-9/2/53.....	Equatorial area around Line Islands. 155° and 160°.
No. 17.....	10/16-11/8/53.....	Around Christmas Island.
No. 18.....	11/21-12/19/53.....	Equatorial area. 155° and 155° to 159°.
No. 19.....	{1/15-1/17/54 } Part 1.....	North of Hawaiian Islands. 160°.
	{1/19-2/6/54 } Part 2.....	North of Hawaiian Islands. 155° and 147°.
No. 20.....	5/11-6/23/54.....	Equatorial area around Line Islands. 157° to 163°.
<i>Charles H. Gilbert:</i>		
No. 15.....	2/18-4/26/54.....	Equatorial area. 110° to 120°, and 155°.
<i>Hugh M. Smith:</i>		
No. 18.....	10/7-11/22/52.....	Equatorial area. 120° and 130°.
No. 19.....	1/8-2/12/53.....	Equatorial area around Line Islands. 157° to 162°.
<i>Cavalieri.</i>	8/13-9/27/52.....	Equatorial area. 140°.

In the collection of data, assistance was rendered by many members of the POFI staff, including the officers and crews of the vessels who had the problem of handling these large and troublesome

¹ Reports of the tuna studies, together with detailed tables of the catch and fishing localities, may be found in Murphy and Shomura (1953a, 1953b, 1955).

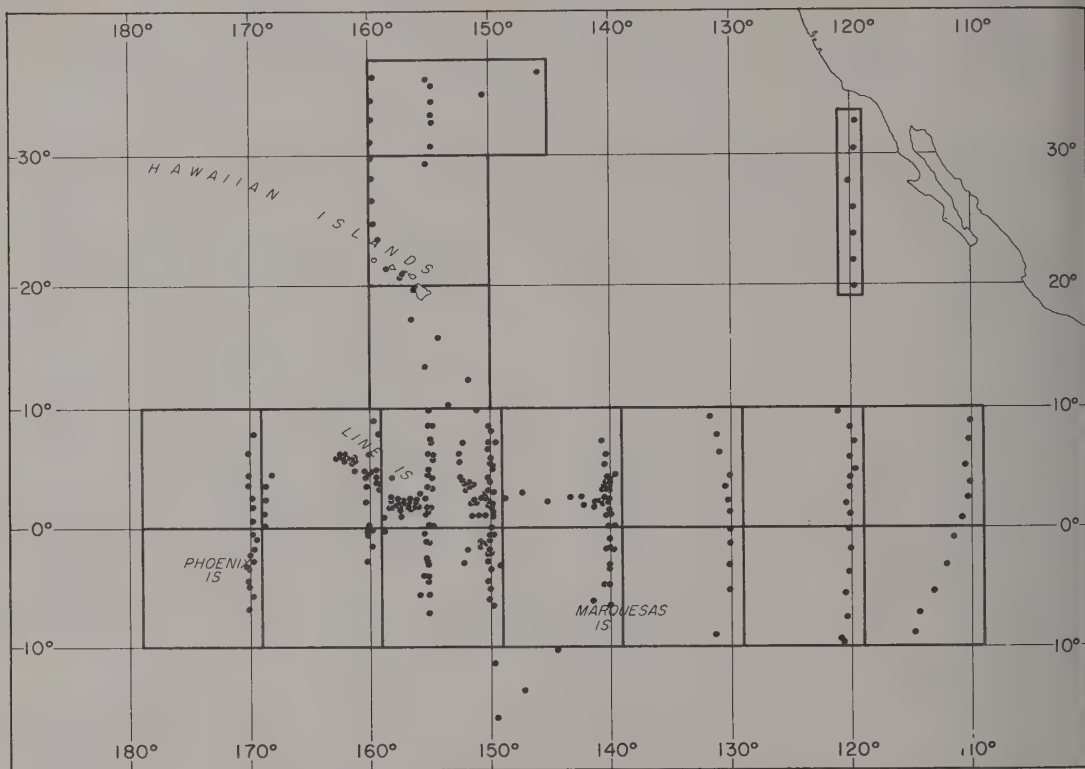


FIGURE 1.—Position of longline fishing stations where spearfish data were obtained.

fish. Many scientific staff members have made observations and those who measured the fish are listed in the appendix. Some people made very special contributions: Vernon Brock, of the Division of Fish and Game, Board of Agriculture and Forestry, of the Territory of Hawaii, in addition to his many helpful suggestions, made available to us observations on the spearfishes recorded by his division, and critically read this manuscript; Wilvan G. Van Campen, Japanese translator for POFI, brought to our attention and translated various Japanese publications on the spearfishes, which added so greatly to our knowledge of this group; and Daniel T. Yamashita and Dorothy D. Stewart most carefully brought together the observations obtained on the longline cruises and assisted notably in the computations. I am also indebted to Carl L. Hubbs, James E. Morrow, Hiroshi Nakamura, Luis R. Rivas, and Robert L. Wisner, for their critical reading of the manuscript.

SPECIES OF SPEARFISHES IN THE CENTRAL PACIFIC

The separation and naming of the species of spearfishes has been a problem of particular difficulty, because the original descriptions of most of the species are so poor and some of the species are so similar and variable that it is impossible to identify them immediately from the original descriptions. It has been necessary for us to start with identifications made by our fishermen, most of whom are experienced longline fishermen and have seen many marlins. We also have had the benefit of the key to Hawaiian fishes by Brock (1950), which was based on observations of the marlins landed in the Hawaiian market.

The fishermen of Hawaii recognize six species of spearfishes to which they have given the English names of black marlin, silver marlin, striped marlin, Indian spearfish, sailfish, and broadbill swordfish. After seeing several hundred speci-

mens which included all of these spearfishes, we concur with the fishermen that these are six clearly distinct and easily recognizable species. All of them are fishes of the high seas, and seem to be the same in Hawaiian waters as along the Pacific Equator, where we have caught them in considerable numbers. They fit so well the descriptions given by Nakamura (1949) that there seems little doubt that they occur also in the western Pacific from Japan to Australia. Furthermore, the description of the marlin fishing off Acapulco, Mexico, given by Gabrielson and LaMonte (1950) indicates that the Acapulco "black" marlin is similar to the Hawaiian "black" marlin and that the "silver" marlin and "striped" marlin of Hawaii also occur in Mexican waters. South of the Equator off Peru, Chile, New Zealand, and

Australia, there appear to be two common species of marlin: a "striped" marlin comparable to the "striped" of Hawaii, and a "black" marlin, similar to the one called "silver" in Hawaii and "white" in Japan. A third marlin, similar to the "black" marlin of Hawaii and Japan has been described from New Zealand by Griffin (1927) and from Australia by Whitley (1954), but apparently it is not as common as the other marlins in the Southern Hemisphere. In the discussion to follow, a single common name will be used for each species to avoid confusion.

The following key ² is based on the subsequent analysis of characters, distribution, and synonymy. Line drawings of spearfishes of different sizes which will aid in identifications are given in figures 2 and 3.

KEY TO THE SPEARFISHES OF THE CENTRAL PACIFIC

- 1a. Snout broad, flattened and long, pelvic fins absent, one pair of keels on caudal peduncle Xiphiidae.
BROADBILL SWORDFISH *Xiphias gladius* Linnaeus.
- 1b. Snout shorter, nearly circular in cross section, pelvic fins present, two pairs of keels on caudal peduncle 2
Istiophoridae
- 2a. First dorsal fin very high with middle rays longest, about as long as head.
SAILFISH *Istiophorus orientalis* (Temminck and Schlegel).
- 2b. First dorsal fin moderate with anterior rays longest, middle rays much shorter than head 3
- 3a. Snout short, tip to anterior edge of orbit about equal to length of mandible. Body slender; greatest depth less than 13 percent of fork length. Not striped on sides. Rarely weighs more than 100 pounds.
SHORTNOSE SPEARFISH *Tetrapturus angustirostris* Tanaka.
- 3b. Snout longer, tip to anterior edge of orbit more than 1.3 times length of mandible. Body stouter, greatest depth more than 13 percent of fork length. Striped or not on sides. Commonly weighs more than 100 pounds 4
- 4a. Pectoral fin rigid, cannot be folded flat against side. Height of first dorsal less than 80 percent of greatest body depth, averaging about 60 percent. Pelvic fins 18 to 31 cm., average 26 cm. in fish over 150 pounds. Rarely striped on sides; stripes never conspicuous after death.
BLACK MARLIN ³ *Istiompax marlina* (Jordan and Hill).
- 4b. Pectoral fin turns and folds flat against side. Height of first dorsal usually more than 70 percent of greatest body depth. Pelvic fins 22-42 cm., average about 33 cm. in fish over 30 pounds. Stripes on sides usually visible for a few hours after death. 5
- 5a. Height of first dorsal lobe less, usually much less, than greatest body depth. Height of first anal fin more than 76 percent height of first dorsal, average 86 percent. Height of 20th ray of first dorsal 3-9 cm., average 6 cm. above fin sheath in fish more than 2 m. fork length. Body stouter, more cylindrical. Stripes usually present, but seldom conspicuous after death.
PACIFIC BLUE MARLIN ⁴ *Makaira ampla* (Poey).
- 5b. Height of first dorsal lobe more than 90 percent of greatest body depth. Height of first anal fin less than 76 percent of height of first dorsal, average 66 percent. Height of 20th ray of first dorsal 7-14 cm., average 10 cm. above fin sheath in fish more than 2 m. fork length. Body more slender, compressed, and tapered. Stripes usually conspicuous after death.
STRIPED MARLIN *Makaira audax* (Philippi).

² Refer also to the complete discussions referring to specimens weighing less than 50 pounds.

³ White marlin of Japan, silver marlin of Hawaii, black marlin of South America, Australia, and New Zealand.

⁴ Blue marlin of Atlantic Ocean, black marlin of Hawaii and Japan. We follow LaMonte and Marcy (1941) in the use of the name *ampla* and have not tempted to unravel the tangled synonymy of the Atlantic form.

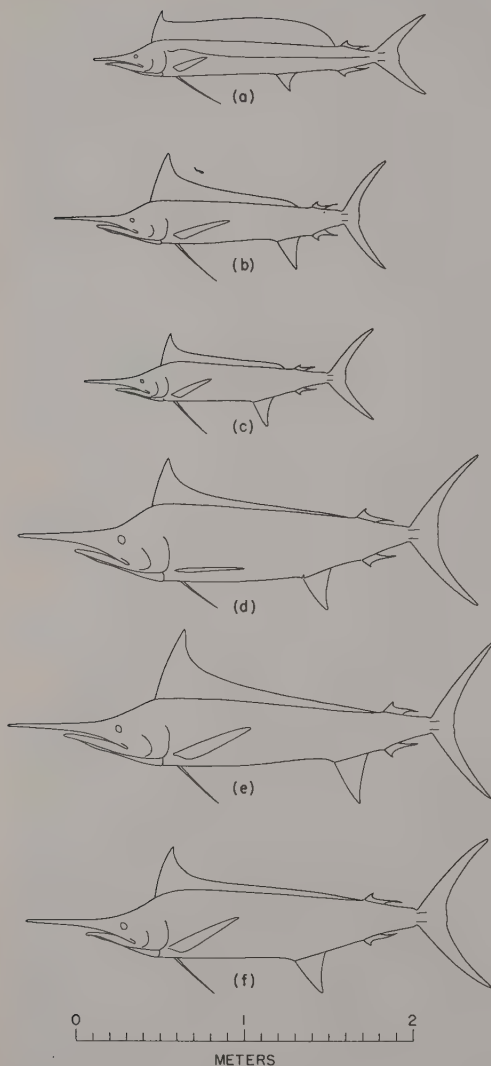


FIGURE 2.—The body proportions at 50 pounds of (a) *Tetrapturus angustirostris*, (b) *Makaira audax*, and (c) *Makaira ampla*; and at 200 pounds of (d) *Istiompax marlina*, (e) *Makaira audax*, and (f) *Makaira ampla*.

ANALYSIS OF DIAGNOSTIC CHARACTERS

It is obvious from an examination of the literature on marlins and from study of a few specimens that a proper designation of the species can be made only after a suitable account of the variation in diagnostic characters. All too fre-

quently casts or photographs of single specimens have been used to describe new species and subspecies. The danger of such a practice has been shown by Conrad and LaMonte (1937) and Gregory and Conrad (1939), who measured numerous specimens of three species from restricted localities and found marked variation in body proportions in each species. Furthermore, since Shapiro (1938) and Morrow (1952a) demonstrated marked changes in certain proportions due to allometric growth, it is dangerous to use ratios to describe the size of body parts.

Of the spearfishes, the marlins are the species of most concern, and the numerous authors who have considered them have tried to recognize their differences with a great variety of external characters. These characters have included the proportions of the head with its unique sword, body proportions, length or height of certain fins, character of the lateral line, color patterns, and in a few instances, the number of rays in certain fins. Also, it has been observed repeatedly that the pectoral fin of certain marlins cannot be folded against the body, whereas the pectorals of other marlins fold readily. The work of Nakamura (1938) has shown that considerable differences in bone structure account for this variation in flexibility.

SOURCE OF THE DATA

There is now available a considerable amount of material for morphological comparison which includes the 12 sets of measurements of *Istiompax marlina* and the 30 of *Makaira audax* from New Zealand and Australian waters recorded by Gregory and Conrad (1939); also the 23 sets of measurements of the Atlantic blue marlin, *Makaira ampla*, obtained at Bimini, Bahama Islands, in July 1937 and reported by Conrad and LaMonte (1937). Morrow (1952a) gave a few measurements for 49 *audax* from New Zealand. From our POFI collection, we have measurements of 11 *marlina*, 68 *ampla*, 25 *audax*, 6 *Istiophorus orientalis*, and 8 *Tetrapturus angustirostris* (appendix tables 1-A to 1-E, p. 541). Almost all of these spearfishes are from the central equatorial Pacific waters. In addition, Vernon Brock of the Hawaiian Division of Fish and Game (DFG) has made available to us certain measurements from 5 *marlina*, 27 *ampla*, 30 *audax*, and 2 *angustirostris* (appendix tables 2-A to 2-D, p. 548), obtained from

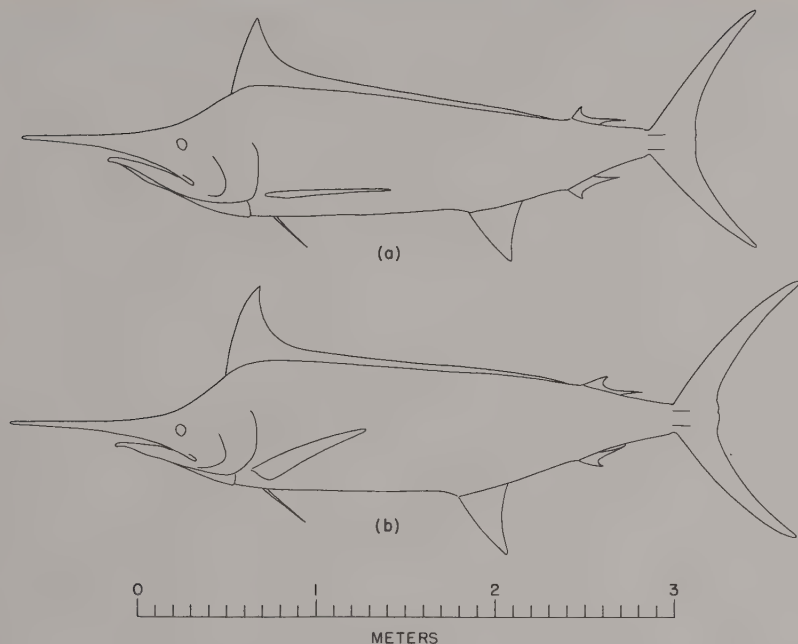


FIGURE 3.—The body proportions at 800 pounds of (a) *Istiompax marlina* and (b) *Makaira ampla*.

fish landed at the Honolulu market and which, undoubtedly, were caught within 200 miles of the Hawaiian Islands.

From many of the POFI specimens we obtained notes on food and sexual condition, which are summarized in the discussions under the species. Also, for several specimens not listed in the appendix, length and weight data were obtained which have been used together with listed observations to compute the length-weight relation.

Considerable material on the weight of spearfishes landed at the Honolulu auction market has also been made available by the Hawaiian Division of Fish and Game. This consists of weights of individual fish identified and recorded by dealers who allowed their records to be copied. These data show the range of sizes, seasonal trends, and modal sizes landed in Honolulu. These weights are slightly less than live weights, however, because the swords, pectorals in *marlina*, and sometimes the lobes of the tail are removed before delivery to the market. Also large fish are frequently cut in two or more pieces so that they have lost body fluids.

All measurements taken by POFI and by the Hawaiian Division of Fish and Game have been

obtained with sliding calipers read to the nearest millimeter. All measurements are the shortest straight line between the points specified. No attempt was made to obtain offset measurements parallel to the midline of the body. The fish to be measured were laid on their sides in as natural a position as possible with the jaws shut and with the snout propped up so that the sword was an extension of the midline of the body.

The POFI measurements were taken by people accustomed to measuring tunas according to the methods of Marr and Schaefer (1949). Where applicable, the same methods were followed in measuring the spearfishes, but certain morphological differences required special definition. The orbit was measured instead of the iris and it was measured parallel to the midline of the body. The depth of the head was measured from the supra-occipital (which may be felt easily) to the throat on a line perpendicular to the midline of the body. The heights of the first anal and first dorsal fins were measured from the top of the fin sheath, and the posterior end of the fin was considered to be the end of the fin groove. The length of the mandible was measured from the tip to the posterior end of the mandibular bone at the joint,

which can be found easily by moving the jaw. The body width was usually measured when the fish was balanced on its belly but occasionally when the fish was on its side.

Having in mind the difficulty in sexing *Xiphias gladius* reported by LaMonte and Marcy (1941), we expected that the marlins also might be troublesome. We have, however, encountered large numbers of marlins in which the eggs or milt were unmistakable, and on examination of the mature gonads of these fish we found differences that make it possible to determine the sex with assurance. The most obvious difference is the presence of a firm, connective-tissue sheath around the ovary that is lacking in the testis. The inactive testes superficially resemble the fatty tissue of mammals. They are usually approximately cylindrical, but when bent can be seen to be distinctly lobed and without a sheath. On the other hand, the inactive ovaries are also roughly cylindrical but have a definite sheath and no evidence of lobes. When an ovary is cut, the interior is usually orange in color and appears distinctly granular to the naked eye due to ova in early stages of development. We have noticed no external sexual differences, except that in *marlina* and *ampla* all specimens of more than 322 pounds have been females.

DETERMINATION OF ALLOMETRIC GROWTH

In view of the known allometric growth⁵ in some parts of marlins it is desirable to examine each diagnostic measurement to determine if allometry exists. If so, it will be feasible to compare samples only at specified body sizes, which usually is done from regression equations. If the growth is isometric we can use ratios. In addition, it will be shown that the size of certain parts is completely unrelated to the size of fish (within the range of fish sizes studied) and that it is possible to compare samples by use of the simple length frequency and mean size.

⁵ We follow what we believe to be the intent of Huxley and Teissier (1936), who proposed that allometry be used in place of other terms to denote growth of a part at a rate different from that of the whole. This they defined to be the case where the relative growth could be expressed by a formula of the type $y = bx^a$ with $a \neq 1$, in which y is the part, x the standard or whole, and a and b are constants. When $a = 1$, growth would be considered to be isometric.

We have used a growth equation of the type $y = a + bx$, and have considered growth to be allometric when $a \neq 0$, and the ratio of part to whole changes with size of the whole. When $a = 0$, the ratio is constant and the growth is considered to be isometric. This is consistent with the proposal of Huxley and Teissier because, if $a \neq 0$ and the line is extrapolated from the data to the zero point, a curve results, and if the formula $y = bx^a$ is applied, then $a \neq 1$.

A determination of allometric growth sufficiently accurate for our purposes can be had from a plot of each character on graph paper. When the points are in place, it is a simple matter to fit by eye a trend line (curved if need be) and then draw two other lines from the origin representing constant ratios near the upper and lower boundaries of the distribution. It is convenient if the boundary lines are drawn to represent even percentages of the abscissal character. Now, if growth is isometric the trend line will be straight, pass through the origin, and approximately bisect the angle of the outer lines. If growth is not isometric, the trend line will curve or cross one or both of the outer lines and it is possible to judge approximately how much the ratio changes over the range of the data. In the marlin data, we found it easy to judge when the trend line changed over the range of the data more than about one-third of the difference between the boundary lines. When the change was greater we used straight-line regression analysis. When the trend line was curved we omitted part of the data and used only that from the straight portion.

Such approximations are adequate for our purposes for two reasons: (1) We are concerned here principally with differences among species and not the minutiae of racial or subspecific differences, and (2) some of the marlin measurements show curvilinear relationships which our samples are not adequate to describe precisely and which cannot be dealt with easily through the logarithmic growth equation.

An example of the method is the plotting of the length of the pectoral fin against the fork length, using the data from the POFI collections (fig. 4). Use of this character is appropriate because Morrow (1952a) found a slight, although not statistically significant, negative allometry in this character. We notice in our plot which includes small specimens of *audax* and *ampla* that the growth is probably curvilinear in both of these species. But if we omit the specimens of less than 200 cm. fork length, the evidence of allometric growth is very small indeed. There is a suggestion that the length of the pectoral in *audax* increases or shows a slight positive allometry (contrary to Morrow's finding), whereas in *ampla* and *marlina* the allometry appears to be trivial. However, if we omit the small specimens, the trend in any one species changes only

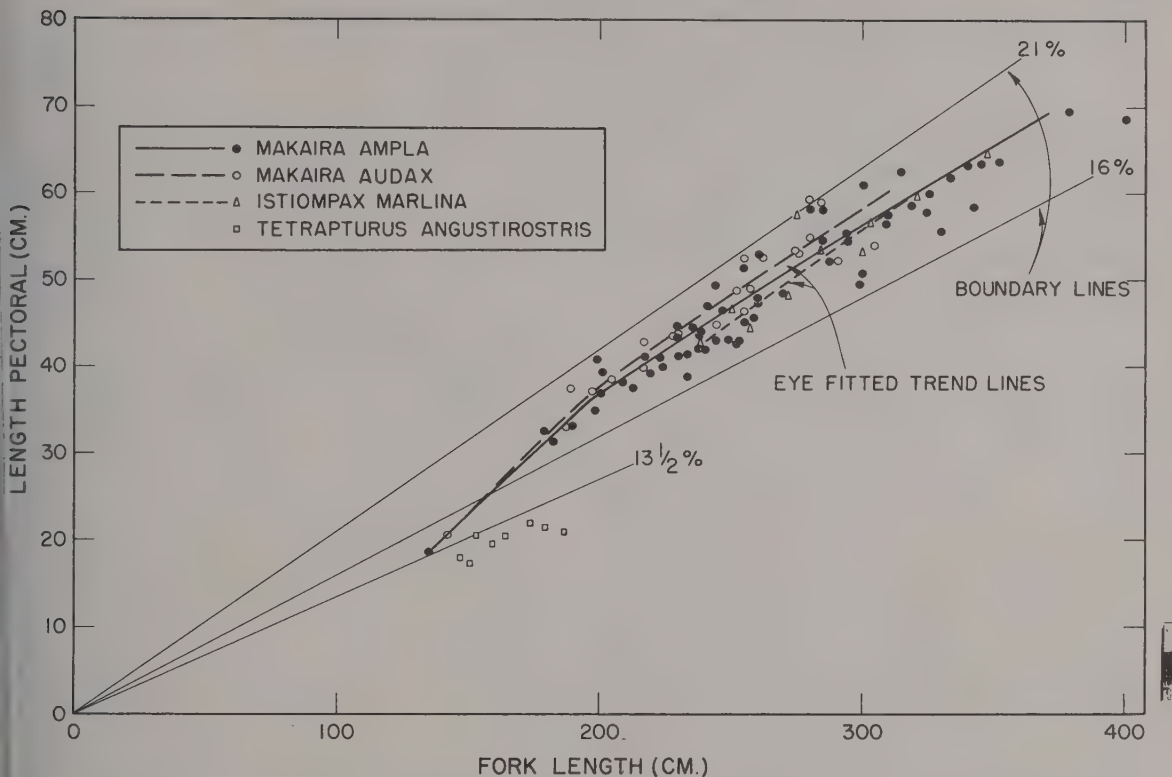


FIGURE 4.—Relation of length of pectoral fin to fork length. (Measurements by POFI have been supplemented by measurements of the Hawaiian Division of Fish and Game (DFG) on specimens between 150 and 200 centimeter fork length.)

about one-fourth of the spread of the distribution. Therefore, we consider that it is satisfactory to compare pectoral fins by using the ratio, or percentage, of fin length to fork length for specimens of more than 200 cm. fork length. (Figure 4 demonstrates, however, that this character is of no value for separation of species.)

An example, in which a considerable amount of allometry is to be found, is that of the greatest depth of body plotted against fork length, again from the data collected by POFI (fig. 5). There is quite obviously a considerable positive allometry in *audax* and *ampla*—which is as expected from the observations that these species tend to become more humpbacked in the larger individuals. We, therefore, conclude that if we use the relative depth of the body we must use regression analysis. Straight-line regressions are satisfactory, for there is no visible curvilinearity within the range of our data. Another obvious

conclusion is that other measurements may be compared to the depth of the body in a simple ratio only if they happen to grow proportionately to it.

Using the graphic technique, we have decided that the following body-part relationships are sufficiently isometric over the range of our samples to permit the use of simple ratios for comparing species: (1) Tip of the snout to the anterior edge of the orbit in relation to the length of the head; (2) height of the anterior lobe of the first dorsal to fork length; (3) length of pectoral to fork length; (4) caudal spread to fork length; and (5) height of the anterior lobe of the first anal to the height of the anterior lobe of the first dorsal. It is necessary to use regression analysis for the relation between the greatest depth of the body and the fork length, the head length and the fork length, the height of the anterior lobe of the first dorsal and the greatest body depth, and

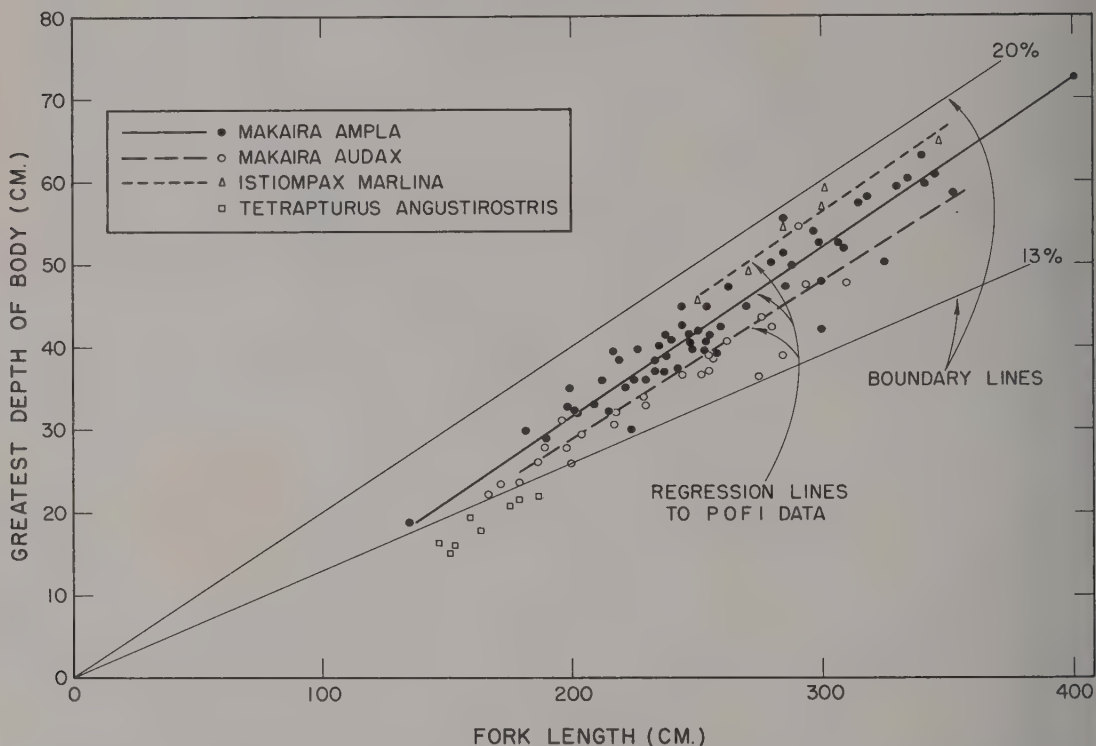


FIGURE 5.—Relation of greatest depth of body to fork length. (Measurements by POFI supplemented by measurements of the Hawaiian Division of Fish and Game (DFG) on specimens between 150 and 200 centimeter fork length.)

the length of the mandible and the length of the snout, measuring the snout from its tip to the anterior edge of the orbit.

Another method must be used to compare the lengths of the pelvic fins (fig. 6). We find no relation between the length of the pelvic fin and the length of the fish, even in the case of the POFI data on *ampla* with specimens ranging from 28 to 1,002 pounds. Thus, our samples may be compared simply by the mean lengths of the pelvic fin.

Finally, in a comparison of the length of the 20th ray (about the middle) of the first dorsal fin (fig. 7) to the length of the fish there is clear evidence of negative growth. This ray is the longest in small (25-pound) specimens of *audax*, but it becomes not merely relatively but actually shorter as the fish increases in size. A similar but not so pronounced a trend is evident in *ampla*. We have compared samples with regard to this character by averaging the length of the 20th

rays in fish over 200 cm. fork length, since the curves (fig. 7) level off above this size.

COMPARISON OF DATA

The type of growth will determine how the data may be compared. In the case both of isometric growth, where we have used ratios, and of characters not related to total length, which can be compared on the basis of mean lengths, we shall use the graphical method described by Hubbs and Hubbs (1953). This consists of plotting the mean, one standard deviation on either side of the mean, and the range of the observations. We will not use the additional feature of plotting two standard errors on either side of the mean because we shall not be concerned with tests of significance.

On the other hand, the characters exhibiting allometric growth will require the use of regression analysis as discussed by Marr (1955). From the regression equations we will compute the mean size of a character for given sizes of fish and the

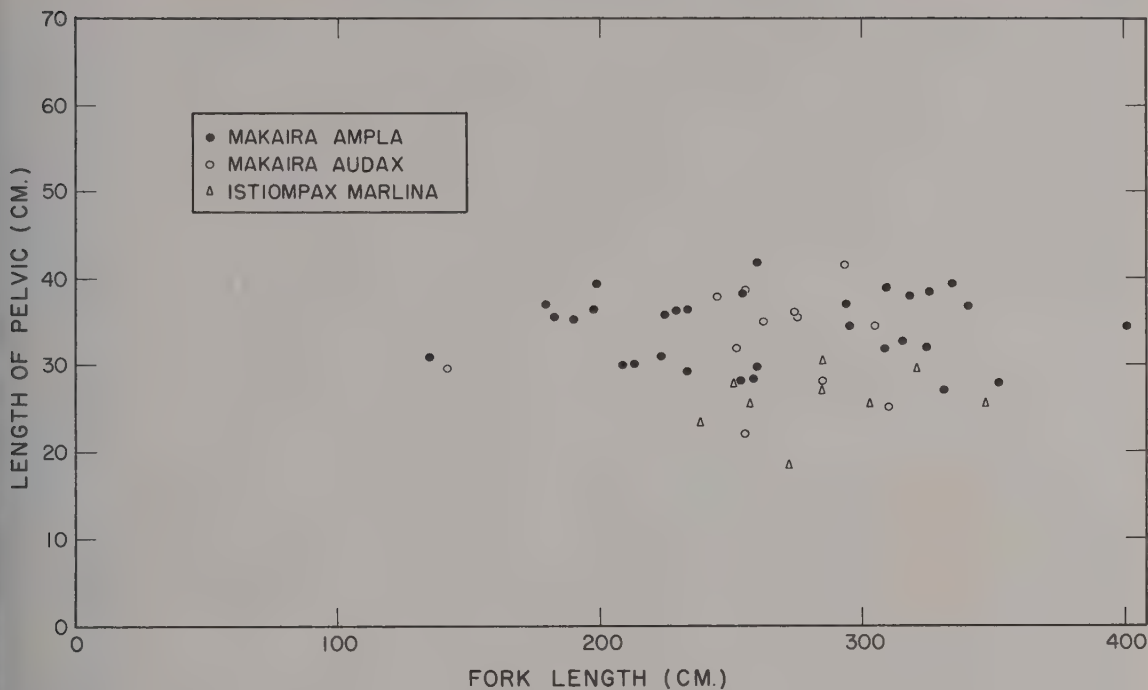


FIGURE 6.—Relation of length of pelvic fin to fork length. (Measurements by POFI.)

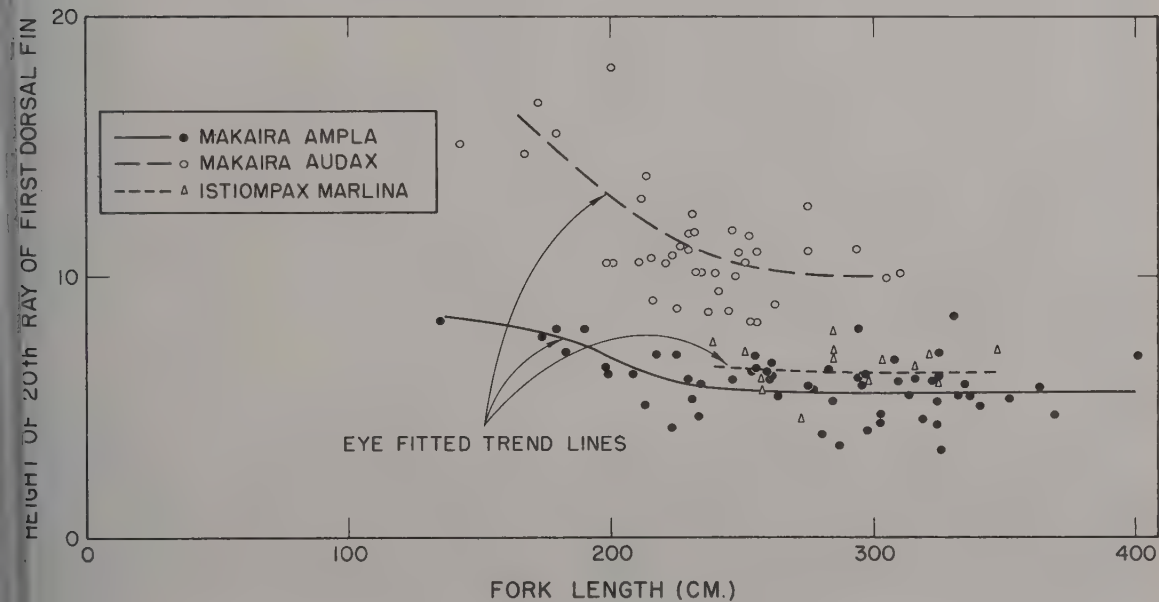


FIGURE 7.—Relation of length of 20th ray of first dorsal fin to fork length. (Measurements by POFI and DFG.)

standard deviation from regression. These will be substituted for the mean and standard deviation in the graphical method of Hubbs and Hubbs. (The range around a point on the regression line is usually not available.) Unfortunately, some samples are so small and the allometric growth so marked that it is necessary to consider some characters at only a single size and others merely from the plotted points on the graph.

CONVERSION OF LENGTHS

Nearly all of the measurements must be considered in relation to other measurements. The best standard is usually length of the fish, but here a difficulty arises. Conrad and LaMonte (1937), Gregory and Conrad (1939), and Morrow (1952a) used body length, measured from the snout to the base of the tail (standard length). Brock, who measured the fish in the Hawaiian market where the snouts are almost always cut off, measured the body length from the naris to the fork of the tail. Measurement from the posterior edge of the orbit to the fork of the tail has been commonly used by Japanese scientists. Thus, a preliminary requirement for examining the characters is to be able to convert from one length to another. We have done this by regression analysis for the three species of marlins, *audax*, *marlina*, and *ampla*, on the basis of POFI measurements. In each case we converted the measurement given to fork length, which is defined as the straight-line distance from the tip of the snout to the tip of the center rays of the tail. These conversions have been made from regression equations (appendix tables 3-A to 3-E, p. 550) on the assumption that straight-line relationships exist between the length measurements. Plots of all measurements for each species have substantiated this assumption.

CHARACTERS

Weight

The general tendency for certain species of the marlins to look heavier than others suggested that it might be possible to separate the species on the basis of the length-weight relation. Nichols and LaMonte (1941) attempted this for the Pacific marlins and they stated that for a given length their striped marlin (*audax*) tended to weigh the least, their silver marlin (*marlina*) more, and their black marlin (*ampla*) most. When the relation is plotted

(fig. 8) for the POFI measurements from the central Pacific,⁶ it is obvious that *audax* weighs less than the other two which are much alike, and that the length-weight relation might indeed be useful for distinguishing individuals of less than 150 pounds. At lengths of about 300 cm. and weights of around 300 pounds, however, there is a great deal of overlap, as the weight of *audax* for a given length then approaches that of *marlina* and *ampla*. In the larger sizes, all three species are so alike that it is impossible to distinguish individuals on the basis of the length-weight relation.

A comparison of POFI data with DFG material and the published data (Gregory and Conrad, 1939; Conrad and LaMonte, 1937; Morrow 1952a) in figure 9 shows that *audax* from all areas is lighter at a given length than the other two species. There is, however, a slightly greater overlap between species at the 300-cm. size, especially for the POFI material in which the specimens of *audax* were slightly heavier at a given length than were those from the other areas.

Greatest body depth

When this measurement is plotted against fork length a marked positive allometry is obvious (fig. 5). Both figures 2 and 10, in which all samples are compared for given lengths, show that *marlina* is deepest bodied, *ampla* intermediate, and *audax* the most slender, but there is considerable overlap between the species. The species *marlina* and *audax* usually can be separated on the basis of body depth, but *ampla* cannot clearly be distinguished from either. Thus, the character is of little value for taxonomic purposes. Within each species there is quite close agreement of the means; and the relative position of the means is almost the same as the mean weights of figure 9, which indicate that the local populations that are heavier for a given length are also deeper bodied.

Head length

Head length has not been used to separate the species of marlins, but Gregory and Conrad (1939, fig. 1) showed that *ampla* has a mean head length of 36 percent of the body length, whereas this ratio in *audax* is about 39 and in *marlina* about 38. Such difference suggests some possibility of separating the species with this character, and also because most head parts are compared with head length, it is desirable to examine our data for allometry

⁶ The data used for this graph include a few specimens not listed in the appendix.

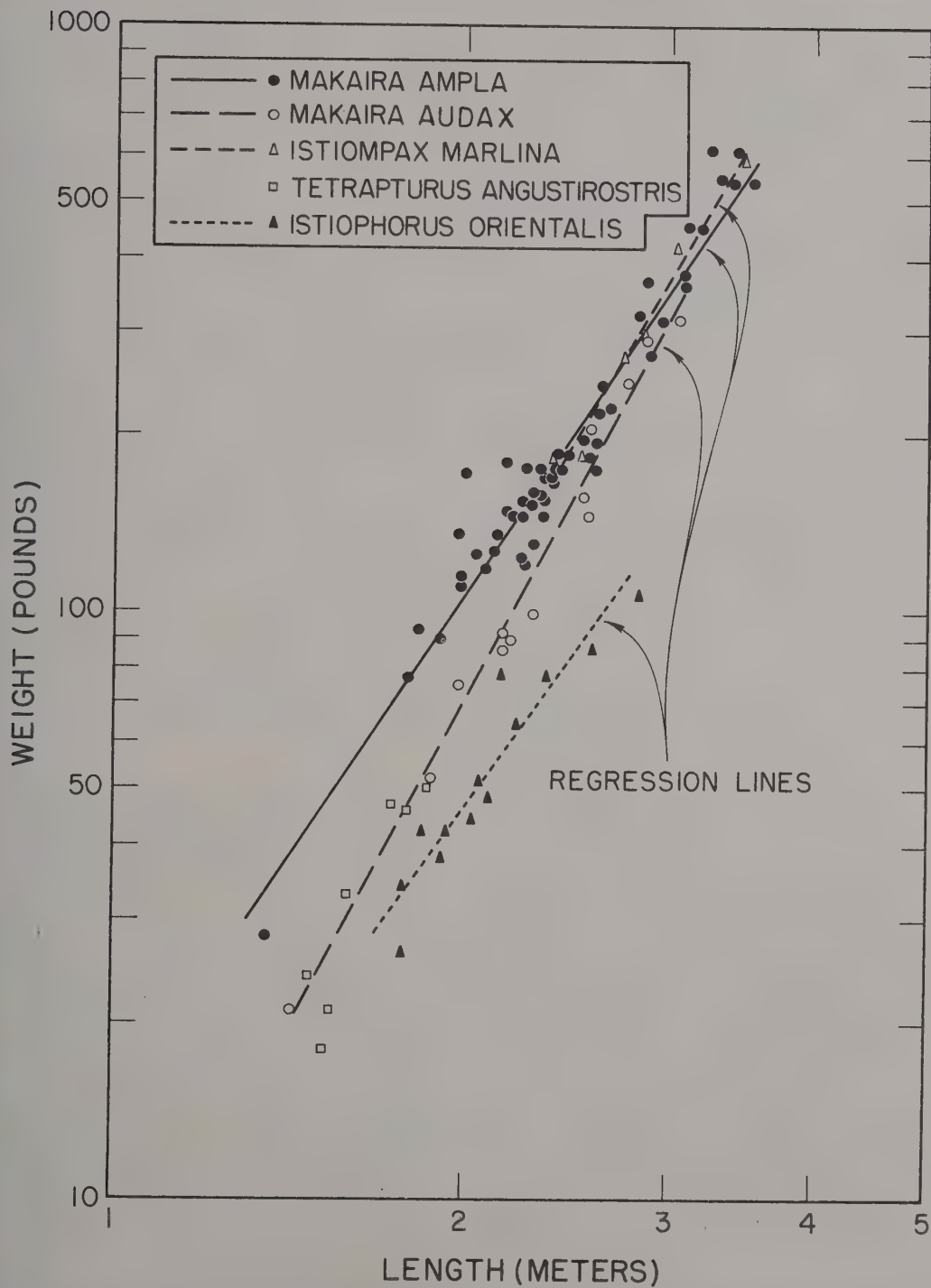


FIGURE 8.—Length-weight relations. No regression line has been computed for the few observations on *T. angustirostris*. (Measurements by POFI.)

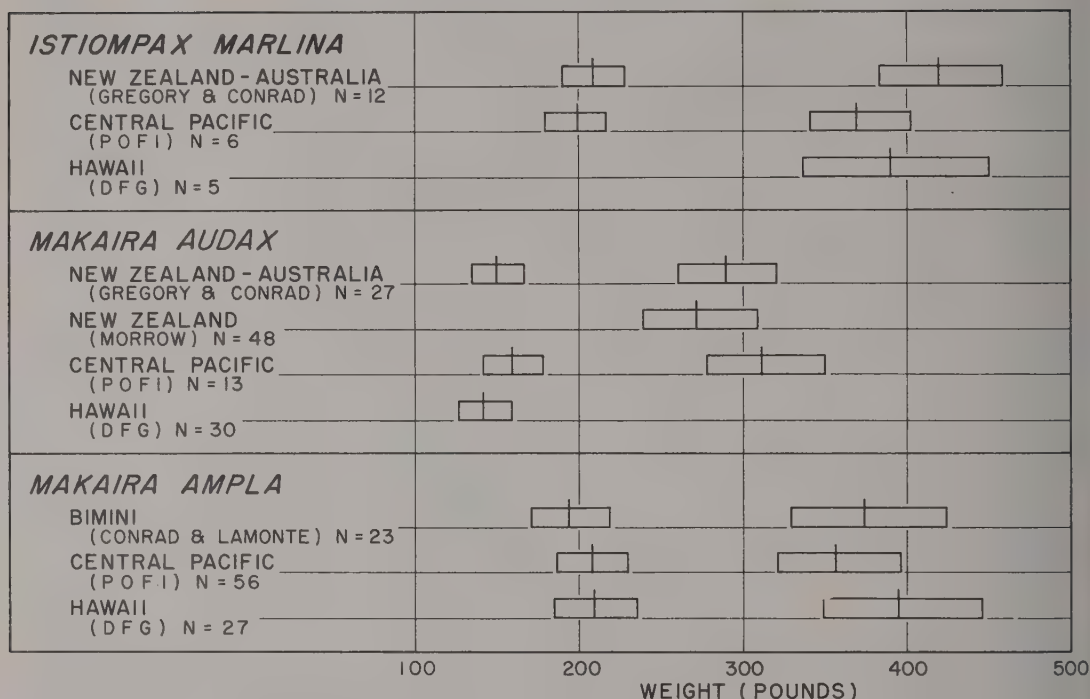


FIGURE 9.—Mean and standard deviation from regression of the weight of marlins at 250 cm. (left) and 300 cm. (right) fork lengths. (Names in parentheses indicate source of data in the literature.)

growth. In the POFI data, head length plotted against fork length shows slight positive allometry in *ampla* and slight negative allometry in *audax*. The condition in *marlina* is intermediate, but too few measurements are available to be conclusive. Therefore, regression methods are indicated for all species.

When we compare the POFI data with those published by Gregory and Conrad (1939) and Conrad and LaMonte (1937), we find good agreement between samples of the same species except that *marlina* from the central Pacific have somewhat longer heads than from the New Zealand-Australia sample (fig. 11). However, the number of samples is so small and the overlap is so great that we consider this difference to be only racial. The differences between species, too, are so slight that the character is almost useless for diagnostic purposes.

Length of snout

Length of snout from front of orbit was used by Jordan and Evermann (1926) as well as by Nichols

and LaMonte (1941) in an attempt to separate these species of fish, no doubt because of the general impression that *marlina* has the shorter and stouter spear and *audax* and *ampla* the longer and slenderer ones. When snout length was compared with head length we found no evidence of allometric growth; hence, we can compare snout lengths by simple ratio. When this is done (fig. 12) for the published data and the POFI data we find that appearances as to snout length are misleading, for all samples of all three species show remarkably similar ratios with the overlap among species and between samples almost complete in all cases. Spear stoutness was not investigated because of the small amount of data. Also, measuring the breadth and width at the tip of the mandible, as we did, is not satisfactory because of the allometric growth of the mandible in *ampla* (see next section).

Length of mandible

When this character is plotted from our POFI measurements (fig. 13), we find a strikingly

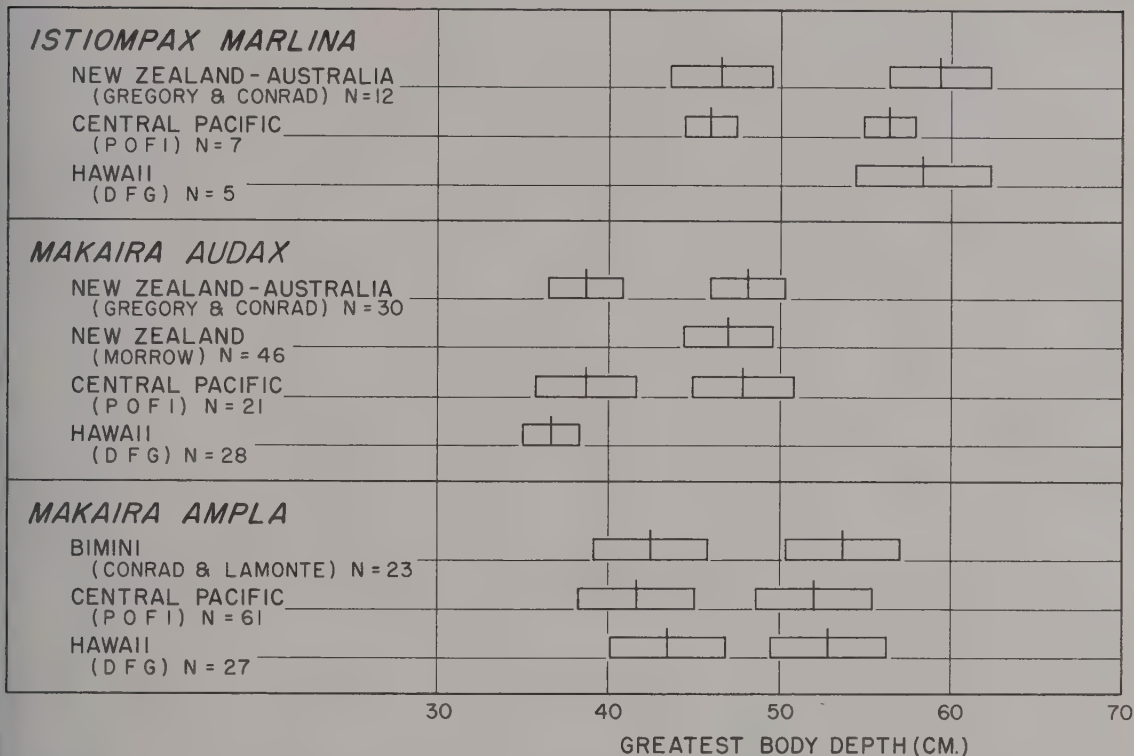


FIGURE 10.—Mean and standard deviation from regression of the greatest body depth of marlins at 250 cm. (left) and 300 cm. (right) fork lengths.

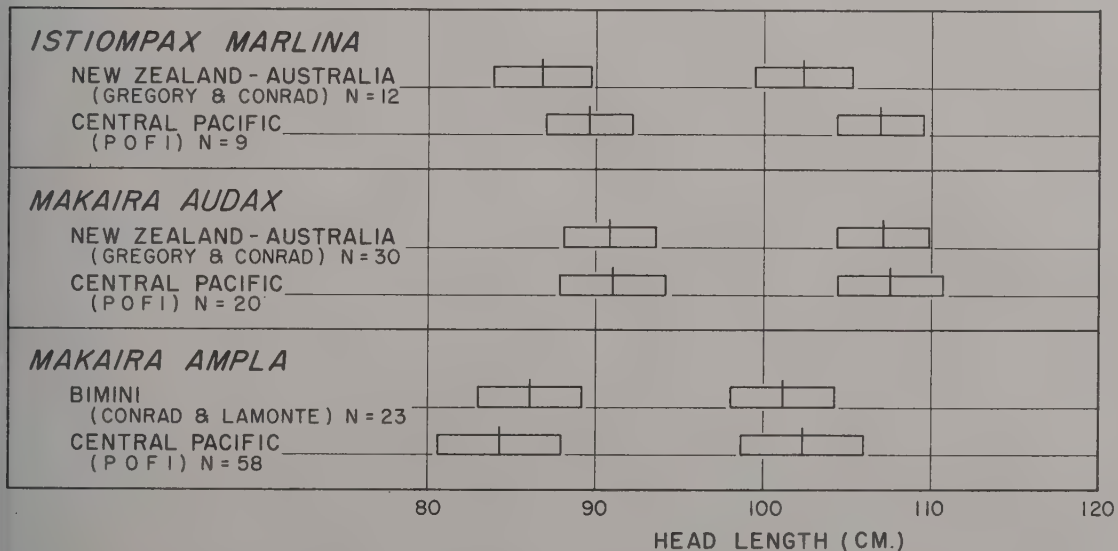


FIGURE 11.—Mean and standard deviation from regression of the head length of marlins at fork lengths of 250 cm. (left) and 300 cm. (right).

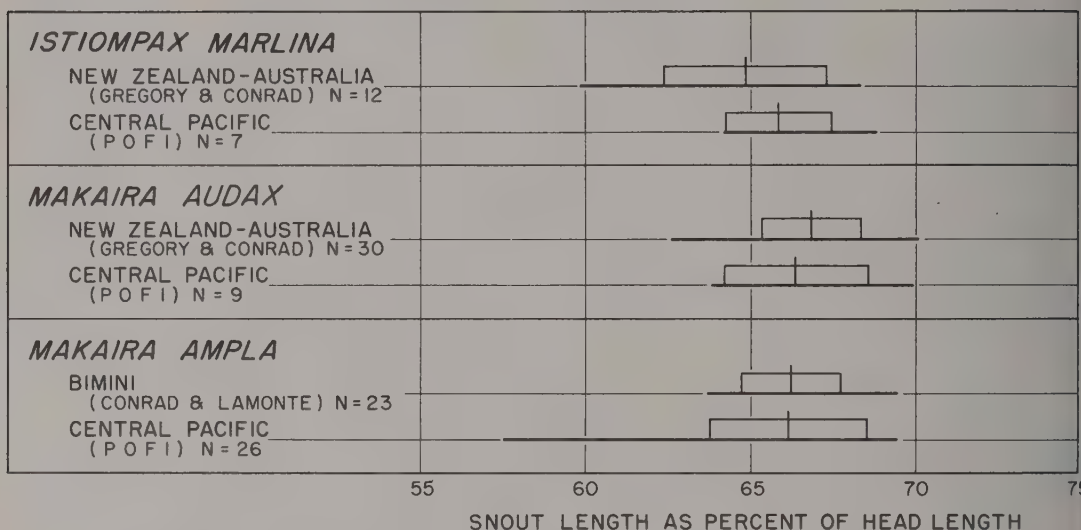


FIGURE 12.—Mean, standard deviation, and range of ratio of snout length to head length.

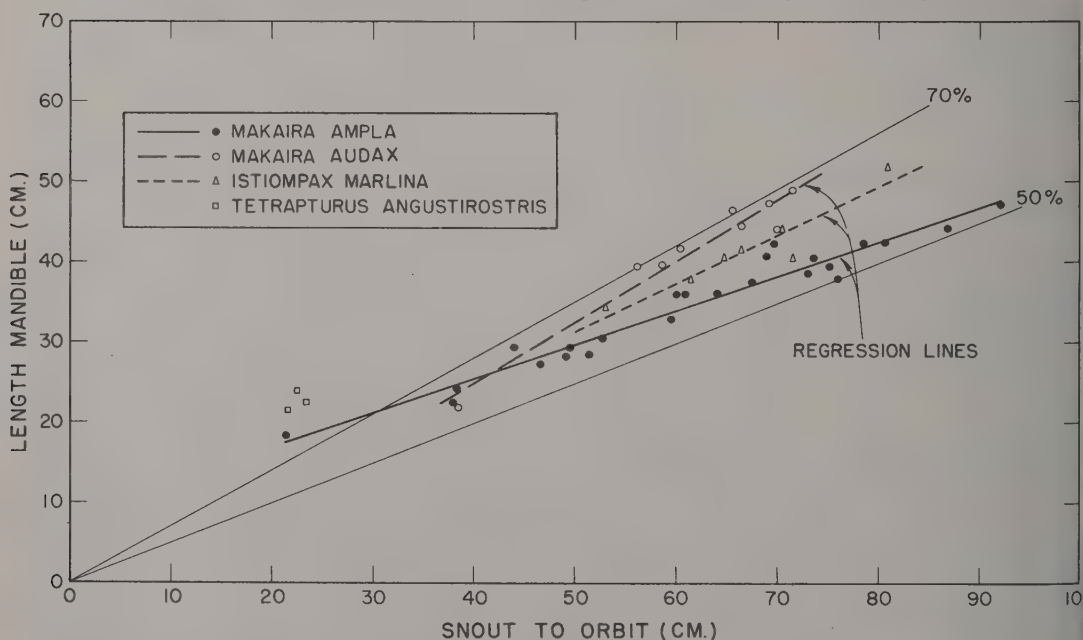


FIGURE 13.—Relation of length of mandible (to the joint) to snout from tip to orbit. (Measurements by POFI.)

different type of growth in *ampla* than in the other two species. The mandible of *ampla* tends to become markedly shorter in relation to the snout as the fish grows, whereas in the other two species the growth is nearly isometric.

A similar relation is apparent when regression lines are fitted to the published data (fig. 14) of Gregory and Conrad (1939) and Conrad and LaMonte (1937). Their data cover a much smaller range than the POFI data but the same

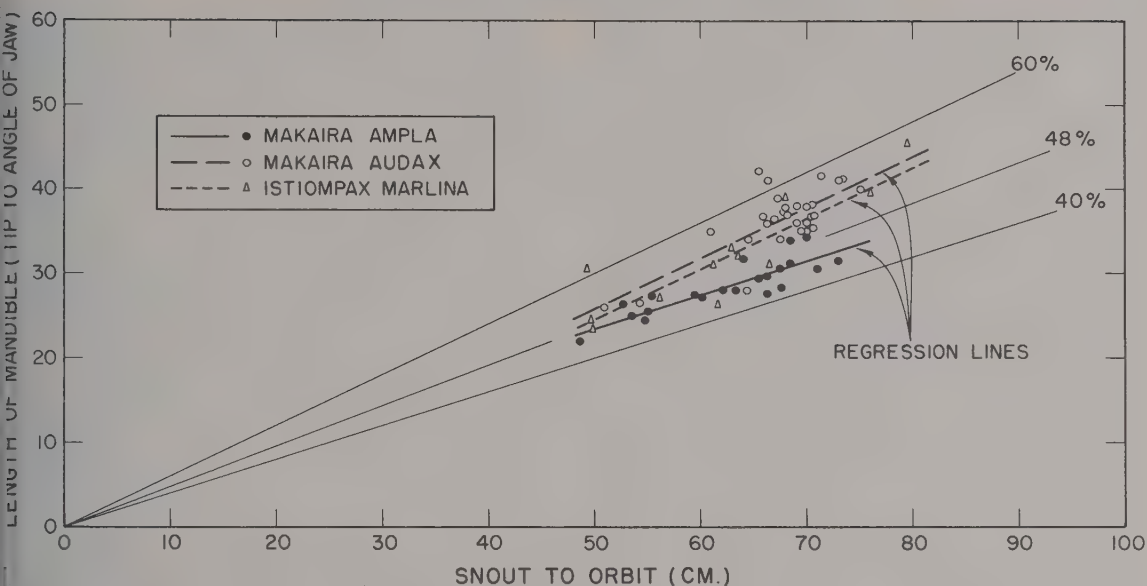


FIGURE 14.—Relation of length of mandible (tip to angle of jaw) to snout from tip to orbit. (Measurements from Gregory and Conrad, 1939, and Conrad and LaMonte, 1937.)

divergence among species is apparent; *audax* and *marlina* show slightly positive allometric growth of the mandible in relation to the snout, whereas *ampla* shows a slightly negative allometric growth. Unfortunately, the POFI measurements of the mandible (to the joint) are not comparable to the measurement used by these authors, so comparisons between areas are not possible.

Obviously, here is a character that is useless for separating the species among the intermediate sizes, but the divergence among the very large specimens suggests that, in them, it may be useful for distinguishing *ampla* from *marlina*. The length of the mandible to the angle of the jaw, as measured by Gregory and Conrad and by Conrad and LaMonte, is preferred to the measurement used by POFI; also, it may be measured with considerable precision from photographs. The plots of the published data suggest that specimens of more than about 600 pounds in which the mandible is more than 48 percent of the snout (that is, goes into the snout less than 2.1 times) will be *marlina*, whereas those in which the length of the mandible is less than 48 percent of the snout should probably be considered to be *ampla*. If we apply this criterion to the type photograph of *marlina* (Jordan and Evermann, 1926: pl. 17; which weighed only 509 pounds), and to all of

Farrington's (1953) photographs of black marlin of more than 600 pounds in which the characters can be measured, we find that the length of the mandible is contained in the snout 1.5 to 1.9 times, with an average of 1.76. On the other hand, in the photographs of *ampla* of more than 400 pounds, shown by Farrington (1937), the length of the mandible is contained in the snout from 1.9 to 2.4 times, with an average of 2.09. Here is a character that may well be useful in distinguishing *ampla* from *marlina*, when the unequivocal character of the pectoral fin has not been recorded; but additional measurements of large specimens are needed to establish the difference.

Clearly, too, this difference in the lower jaw is the reason for the apparent differences that have been observed in the snout. When the lower jaw is very short, as in large *ampla*, the snout seems extremely long and slender, whereas the snout seems shorter when the lower jaw is long, as in *marlina*.

Length of pelvic fin

In our previous discussion of allometric growth, we pointed out that there was almost no change in the length of the pelvic fin with size of the fish in any of the three species examined by POFI. Consequently, we may compare these on

the basis of the average length of the fin and disregard the size of the fish.

We find good agreement between the samples of the same species, but *marlina* has markedly shorter fins on the average than either *audax* or *ampla* (fig. 15). Of the 19 measurements available for *marlina*, the average is approximately 26 cm. and only 1 measurement is more than 30 cm. This is in contrast with the other two species in which the pelvic fins average about 33 cm. and in which we find only 19 out of the 95 measurements less than 30 cm. In most of the samples, the range extends farther from the mean on the lower side than on the upper and we suspect that some of the smaller measurements may be due to broken fins. If a careful watch is kept for broken fins, this character may then be useful to separate *marlina* from the other two species when other characters are not available. Any marlins with pelvic fins longer than 30 cm. are probably not *marlina*.

Length of pectoral fin

Length of pectoral fin also was discussed in the section on allometric growth and it was pointed out that while small specimens appeared to have slightly smaller pectoral fins in relation to fork length, specimens of more than 200 cm. fork length had pectoral fins which grew almost isometrically.

When pectoral fins are compared (fig. 16), it is apparent that they show almost as much variation within species as between species and that the character is useless for distinguishing one species from the other. The means vary from only 18.2 percent in *ampla* from Hawaii to 19.4 in *audax* from New Zealand and Australia.

Height of first dorsal fin

Height of the first dorsal fin appears to be one of the best means of distinguishing the three species of marlins. Nichols and LaMonte (1941) compared the anterior lobe with head length, Jordan and Evermann (1926) usually compared it with the length of the pectoral fin, and Nakamura (1949) with the greatest depth of the body. When we plotted height of the first dorsal in relation to fork length, we found a negligible amount of allometric growth and, hence, we can use it as a ratio. The comparison of all samples (fig. 17) shows that *marlina* has the lowest fin, *ampla* intermediate, and *audax* the highest. The averages are approximately 12, 13.5, and 17 percent, respectively; however, the separation between species is not complete, as there is considerable overlap between *audax* and *ampla* and between *ampla* and *marlina*. The samples show close agreement within species except for *marlina*, in which there is a suggestion of a clinal difference. The specimens from New Zealand and Australia have the highest first

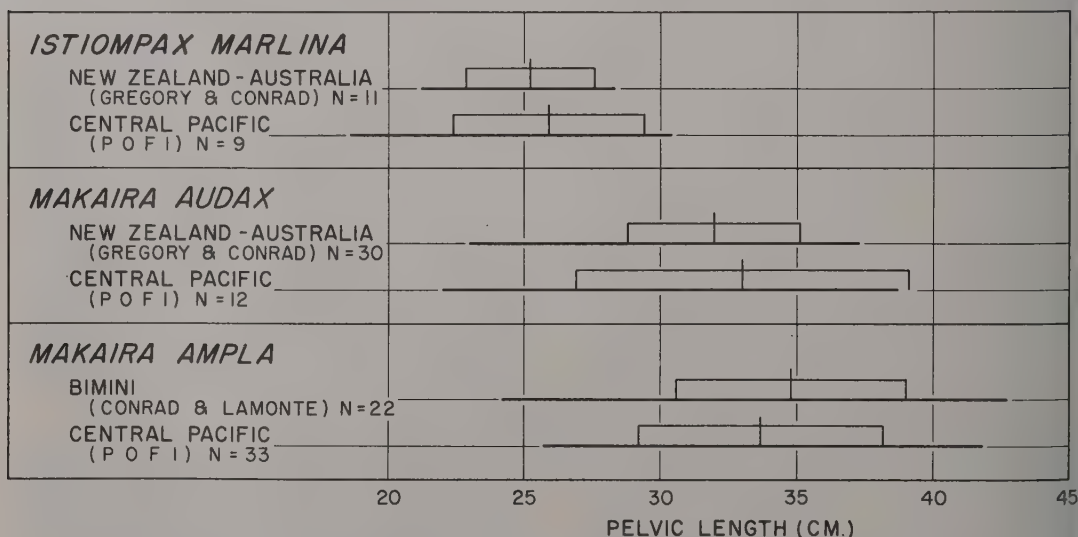


FIGURE 15.—Mean, standard deviation, and range of the length of the pelvic fin.

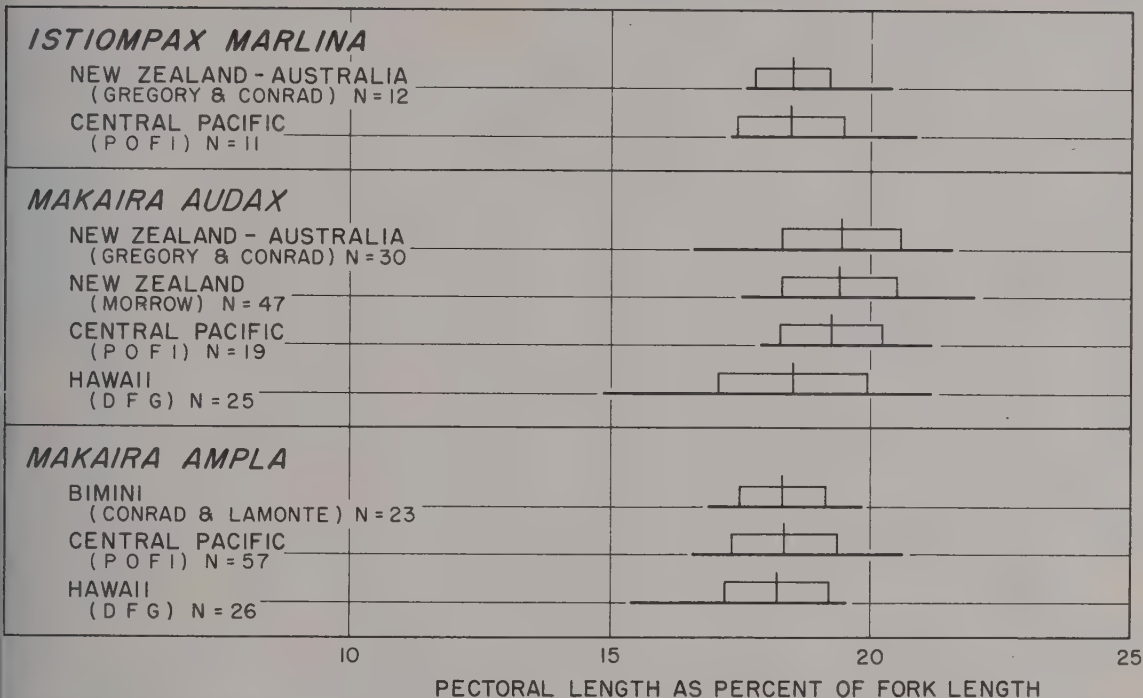


FIGURE 16.—Mean, standard deviation, and range of the ratio of length of pectoral fin to fork length in fish of more than 200 cm. fork length.

dorsal fins, those from the equatorial Pacific lower fins, and those from Hawaii the lowest.

When height of the first dorsal fin is compared with the greatest depth of the body we find a marked allometric relationship (fig. 18). We found no *ampla* in which the height of the first dorsal was greater than the greatest body depth and only one *audax* in which the height of the first dorsal was less than 90 percent of the greatest body depth. The trend lines are such, however, that it is evident that in very small *ampla* the first dorsal may exceed the greatest body depth and in very large *audax* may be less than 90 percent. In any event, there is a considerable overlap of specimens in which the anterior lobe is between 90 and 100 percent of the greatest body depth.

The difficulty presented by allometric growth and most of the overlap between *ampla* and *audax* is eliminated if, instead of comparing the height of the first dorsal with the greatest depth of the body, we compare it with the height of the first anal (fig. 19). Plots of this relationship indicated no allometric growth and hence the comparison

by ratios is valid. This comparison shows that the anal fin in *audax* averages 66 percent of the height of the first dorsal, whereas in *ampla* it averages 86 percent. If we accept 76 percent as a dividing line between the species, we find only a single overlapping specimen of *audax* with a greater value. *Istiompax marlina* is intermediate with an average of approximately 80 percent, and overlaps both of the other species.

Despite the nearly isometric growth of the anterior lobe, the middle of the first dorsal (as indicated by the length of the 20th ray) in *audax* shows not merely negative allometry but actual negative growth, with those fish of less than 200 cm. fork length having a longer 20th ray than the larger individuals. There is a suggestion that the same condition pertains to *ampla*, but the data are too few to verify it. At any rate, the length of this ray changes little in fish of more than 200 cm. and, hence, we compare the samples on the basis of the actual average length of the ray (fig. 20). Here we find the shortest 20th rays in *ampla* and *marlina* and much the longest in *audax*. This character appears to be a fairly

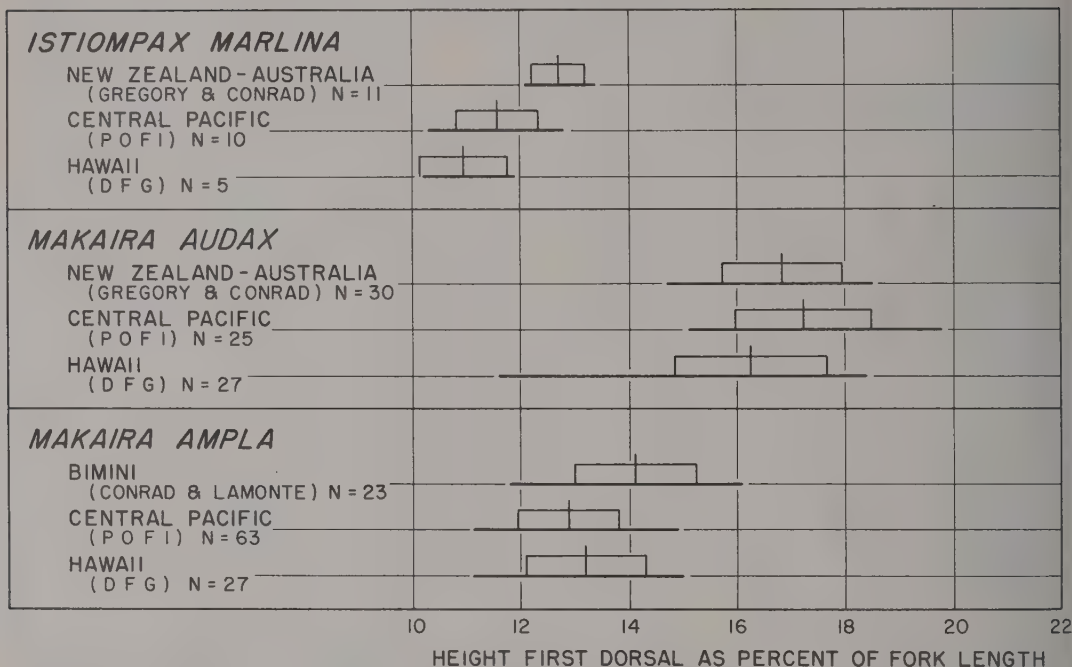


FIGURE 17.—Mean, standard deviation, and range of the ratio of height of anterior lobe of first dorsal to fork length.

good one for distinguishing *audax* from each of the other two species, because with a dividing point of 8 cm. only 1 out of 35 *audax* had a shorter 20th ray and only 5 out of 62 *ampla* had a longer 20th ray. None of the 13 *marlina* had a 20th ray longer than 8 cm.

Caudal spread

When plotted, the caudal spread showed no evidence of allometric growth and, hence, has been compared on the basis of its ratio to fork length (fig. 21). It may be seen that *audax* tends to have the slightly smallest tail, *marlina* intermediate, and *ampla* the largest, but there is so much overlap that the character is useless for distinguishing the species.

There is a persistent tendency for the specimens measured by POFI in each species to have slightly broader caudals than those measured by Gregory and Conrad (1939) and Conrad and LaMonte (1937). All of the POFI measurements, except the one largest *ampla*, were obtained on board ship at sea from fish that had never been lifted by the tail. Consequently, the fin rays had not been compressed and the measure-

ment of the spread might be expected to be slightly greater than if the fish had been handled or hung up by the tail. We suspect that some or all of the fish measured by the authors cited might have been lifted by the tail; consequently, we attach no significance to the slight differences.

Lateral line

Nakamura (1949) has pointed out that *audax* and *marlina* have simple lateral lines, whereas *ampla* has a complex lateral line. We concur in the presence of a complex lateral line in a preserved specimen (specimen No. 1 in appendix table 1-E, p. 545) of *ampla* in which the lateral line is conspicuous. In all fresh material we have examined at sea and in the Honolulu market, we have found the lateral line extremely difficult to locate and to determine whether or not it is complex. We question the usefulness of this character in the field.

Flexibility of the pectoral fin

Many people who have seen *marlina* have reported that the pectoral fin cannot be folded back against the body. Those who have not examined the fish quite naturally have wondered if this

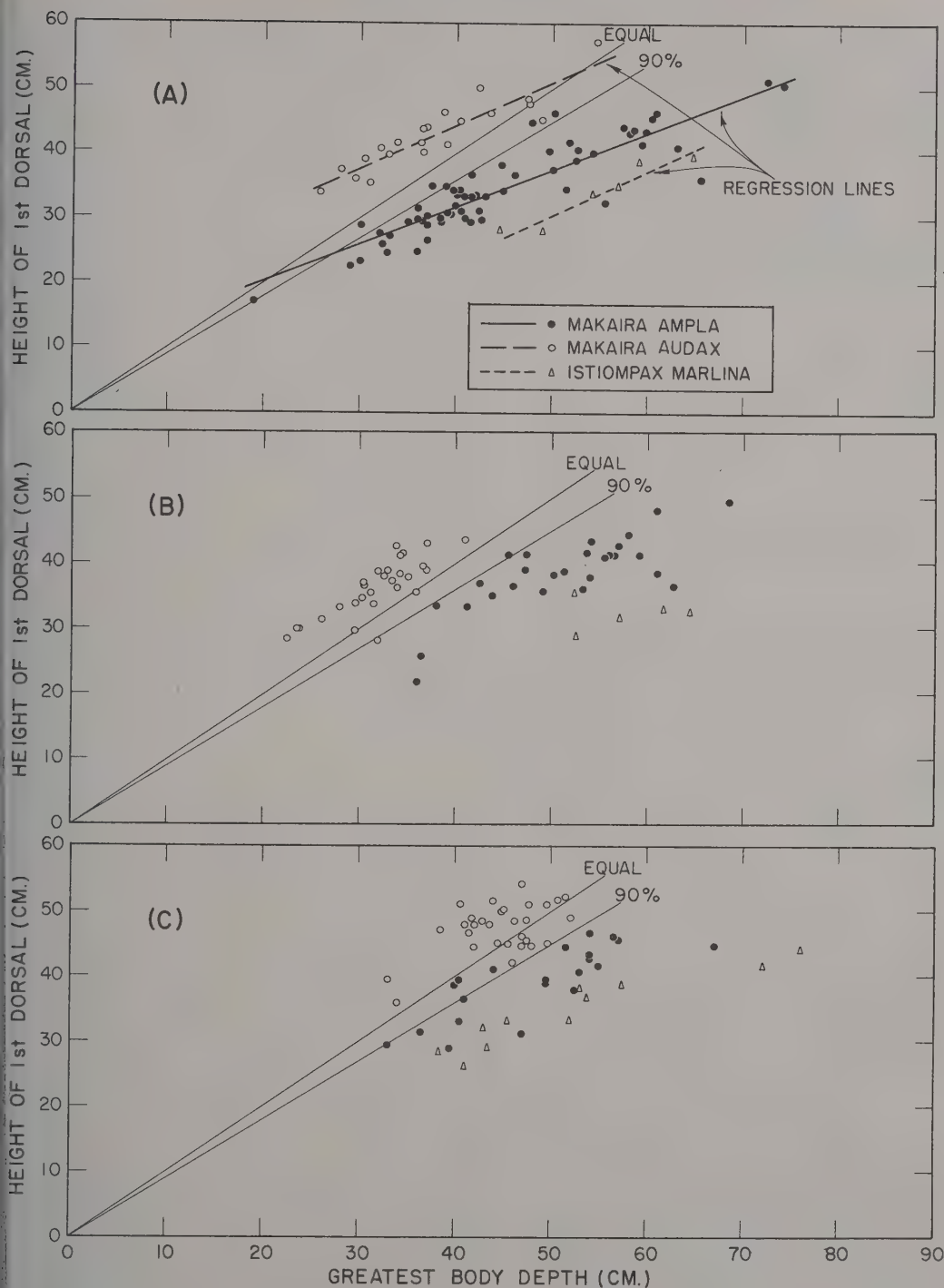


FIGURE 18.—Relation of height of first dorsal fin to greatest body depth. A. Measurements by POFI; B. Measurements by DFG; C. Measurements from Conrad and LaMonte (1937) and Gregory and Conrad (1939). Regression lines have been computed for the POFI data.

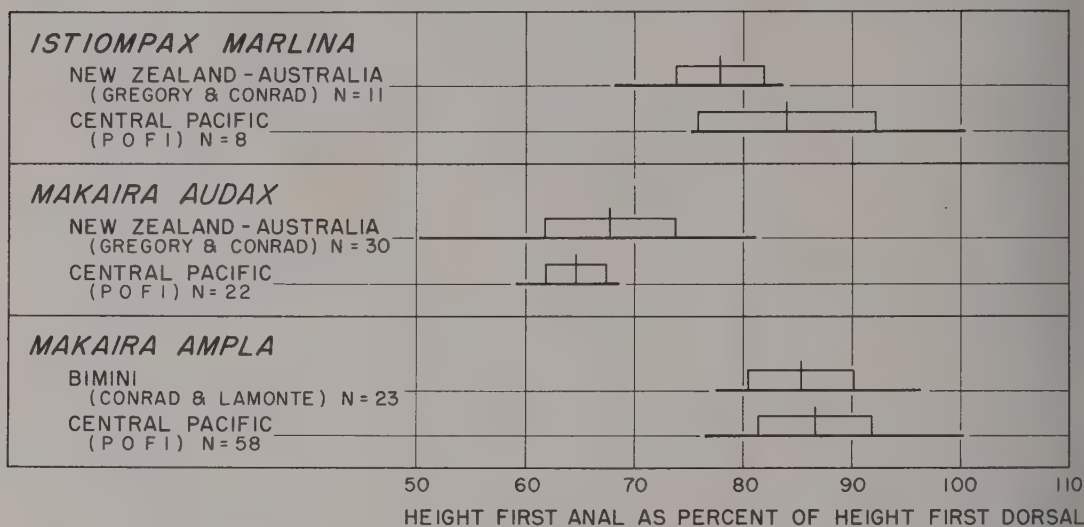


FIGURE 19.—Mean, standard deviation, and range of the ratio of height of anterior lobe of first anal to height of anterior lobe of first dorsal.

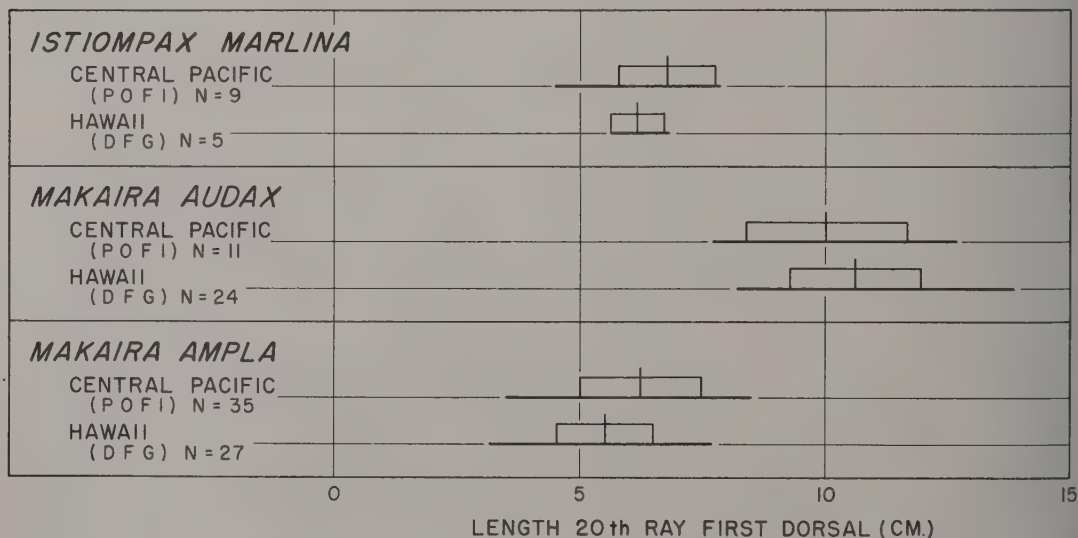


FIGURE 20.—Mean, standard deviation, and range of the length of 20th ray of first dorsal fin in specimens of more than 200 cm. fork length.

condition could arise from rigor mortis or from accidental locking of the joint and thus would not really be a distinctive species character at all. The anatomical work of Nakamura (1938) has established that this fin condition results from osteological structure and not from accidental locking of the fin. Furthermore, after having an

opportunity to compare *marlina* with specimens of *ampla* and *audax* in rigor we do not question the usefulness of the character. The stiff fin of *marlina* can be moved through a limited range but positively cannot be rotated or folded back along the side without breaking. It does, however, move easily in its limited range when not

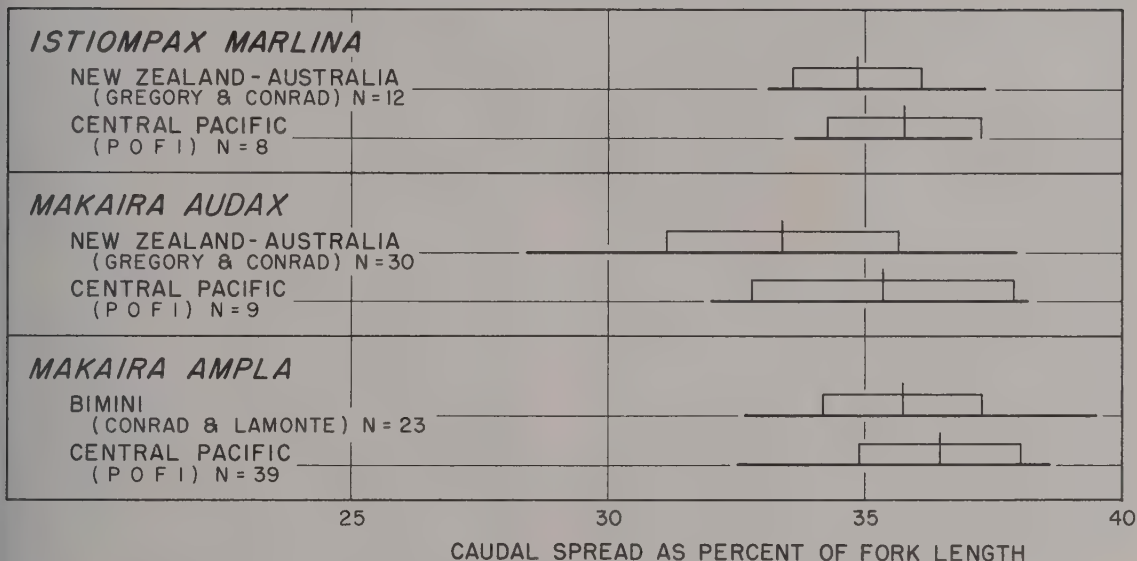


FIGURE 21.—Mean, standard deviation, and range of the ratio of caudal spread to fork length.

in rigor. On the other hand, the pectoral fins of marlins in rigor move stiffly at all times, but we have not yet encountered an *ampla* or *audax*, even though in rigor mortis, whose pectoral fin could not be folded back against the body without breaking.

Miscellaneous characters

We have not used a number of other characters because they are too variable, too similar among species, or our data too few. The depth of the head in *marlina* appears to be greater than in the other species, but when measured from the supra-occipital to the isthmus we found this character to be highly variable. Perhaps this is because it is so difficult to standardize the position of the branchiostegal rays after death. Also, the body of both *marlina* and *audax* appears to be definitely more tapered than that of *ampla*. We attempted to measure this by obtaining a depth at the vent to compare with the greatest body depth but had too few measurements to establish any relation. Then the sword in *marlina* appears definitely heavier and more robust than that of the other two species; but when the breadth is measured at the tip of the mandible we find a great deal of overlap, probably because, as pointed out earlier, the mandible becomes shorter in relation to the sword in *ampla*, whereas in *audax* and *marlina* it grows nearly isometrically. (It would be better

to measure the width and depth of the mandible at the midpoint.) On another occasion, when we had an opportunity to examine a specimen of *marlina* alongside an *ampla* of about the same weight, we noticed that the distance between the ventral groove and the insertion of the anal fin in *marlina* was considerably greater than in *ampla*. However, a few more measurements of this character suggest that it also is extremely variable.

The principal criteria used by Jordan and Evermann (1926) to separate the nominal species properly referable to the genus *Tetrapturus* are the presence or absence of short, stiff spines between the two dorsal fins or between the two anal fins and the width of the interspaces. We doubt the value of these characters in distinguishing the species, because in the few shortnose spearfishes examined we found the interspace between the two dorsals to be highly variable and in one specimen even lacking. We have found no free spines in our specimens of *Tetrapturus*, but have noticed them occasionally in *ampla*, and have even found them in separate fin slots. In most spearfishes the posterior spines of the first dorsal fin become very small, and whether they are separate is not easily determined unless they happen to be in separate fin slots. We consider the interspace between the anals and dorsals and the number of free spines to be of very doubtful value as taxonomic characters.

OBSERVATIONS ON SPEARFISHES OF THE CENTRAL PACIFIC

Having decided which characters are of diagnostic value, it is now possible to consider our observations on the spearfishes of the central Pacific together with the considerable literature on the group from the several parts of this ocean. This we have done in the following discussion, with the assumption that many of the minor differences reported in body proportions will prove to be individual variation, or at most, varietal differences.

During this study we were fortunate to have ready access to Japanese literature through our translator, W. G. Van Campen. He located many papers including several which were published entirely in Japanese. Many of these papers were translated and others were summarized. Further, we corresponded extensively with Japa-

nese workers on the spearfishes and feel that we quite completely covered the recent Japanese literature on the spearfishes.

Xiphias gladius Linnaeus

Swordfish, Broadbill

Tsun, Shūtome, or Mekajiki (Japan)

Our catches of the swordfish have been so small that we can add little of significance; however, it seems worthwhile to discuss it here and give a few brief notes from recent Japanese publications.

The truly pelagic nature of the swordfish is indicated in Kikawa's (1954) review of the Japanese fishery. He reported that at the beginning of the season in late summer the highest catch rates are to be found northeast of Japan, north of

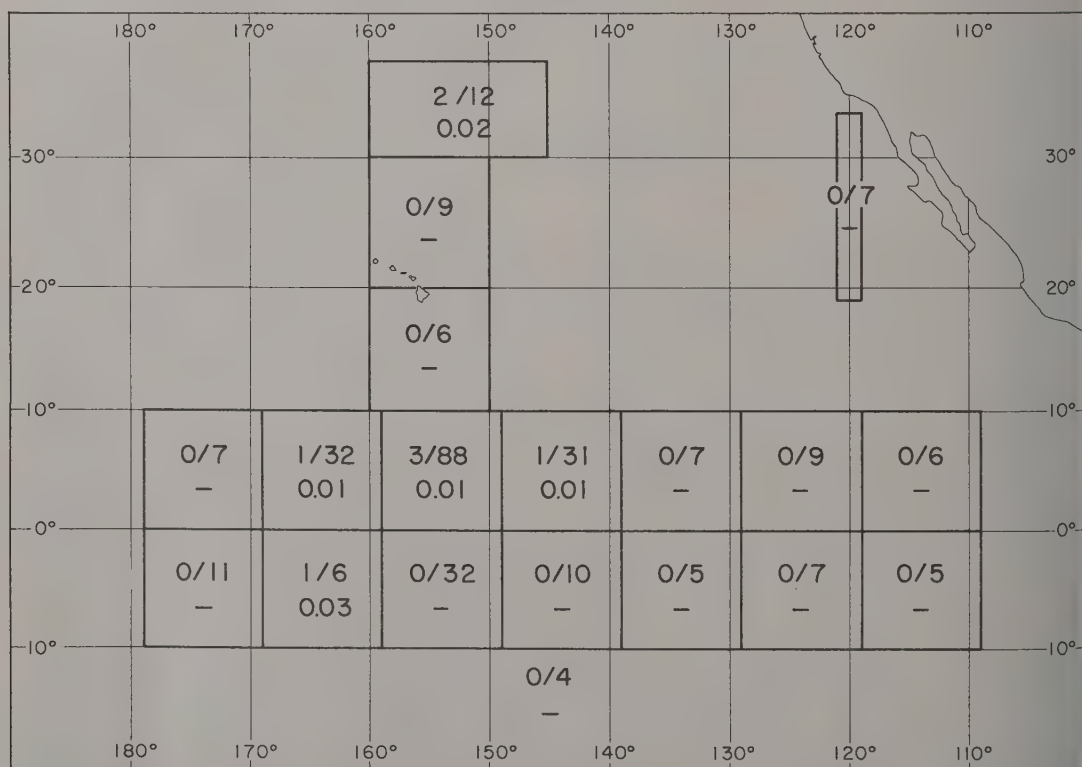


FIGURE 22.—Distribution of POFI catches of swordfish, *Xiphias gladius*. Fractions indicate stations at which catches were reported out of the total fished; decimals indicate average catch per 100 hooks per day.

40° N. latitude, and between 150° and 170° E. longitude. Fishing is carried on at this time north to 45° but, with the advent of winter weather, the fishery moves south to the vicinity of 30° where good fishing is found in December and January. In addition to this offshore fishery there are inshore fisheries around southern Japan and the Bonin Islands, some of which are productive the year round.

The swordfish is generally considered to be an inhabitant of warm seas throughout the world, but its distribution in the western Pacific suggests that the adults prefer the cooler waters. Kikawa (1954) noted that they are only sporadically captured in tropic seas, and this is in agreement with POFI experience (fig. 22) and with the results of the Japanese tuna mothership expeditions to the Caroline Islands area in 1950-51. In the latter, Van Campen (1952) reported that the average catch rate of swordfish for all expeditions was less than .01 per 100 hooks, whereas catch rates off northeastern Japan average nearly 1.0 per 100 hooks (Kikawa 1954).

Nakamura et al. (1951) think that the tropics are the spawning grounds of the swordfish, and noted therefrom the capture of juveniles less than 30 mm. in length and numerous larvae in the stomachs of other fish. They also reported that the longline catches in the equatorial area are predominantly fish from 50 to 100 cm. in length (orbit to fork of tail). In addition, all of the fish in the northern fishery have undeveloped gonads. The presence of small fish in the equatorial area is substantiated by the reports from the Japanese mothership expeditions to the Caroline Islands where, according to Ego and Otsu (1952), the weight of the swordfish captured during each of the first six expeditions ranged from 58 to 102 pounds.

Such catches of large and small swordfish are in accord with the limited POFI experience, for the largest of the three taken in tropical waters on which size data are available was only 80 pounds. The other two were very small, each only 92 cm. long. We also have notes on two small swordfish taken from the stomachs of *Makaira ampla*: one 35 cm. taken on May 18, 1954, at 6°02' N., 152°28' W. and another of 38 cm. taken on May 18, 1954, at 6°02' N., 159°34' W. On the other hand, the two specimens taken north of Hawaii

were each large, more than 300 cm. total length.

Swordfish landed in the Honolulu market (table 2) ranged from 75 to 1,061 pounds, according to the records collected during 1949 and 1950 by the Hawaiian Division of Fish and Game. There was no pronounced mode in this weight distribution.

Additional insight into the habits of the swordfish is available from Kikawa's (1954) account of the methods used in the Japanese fishery. Most of the swordfish are taken by vessels specializing in the fishery that use longline gear similar to tuna gear. The principal difference is in the mode of operation, for these swordfish vessels fish at night when the catch rate is approximately twice what it is in the daytime. Such a difference in the habits of the broadbill makes it difficult to compare these catches with the abundance in other parts of the Pacific, where swordfish are taken by tuna vessels that fish entirely during the day.

TABLE 2.—Weight frequency of swordfish, *Xiphias gladius*, landed at the Honolulu market during 1949 and 1950

[Data collected by the Hawaiian Division of Fish and Game]

Weight group (pounds)	Number weighed in—		Total
	1949	1950	
60-69			
70-79	1		1
80-89			
90-99	2		2
100-109	2		2
110-119	2		2
120-129	2	1	3
130-139	4		4
140-149	3		3
150-159	1		1
160-169	1		1
170-179			
180-189	1	1	2
190-199	2		2
200-219	2	3	5
220-239	1		1
240-259	2		2
260-279		2	2
280-299	1		1
300-319	2	3	5
320-339	4		4
340-359	1	1	2
360-379	3		3
380-399	1		1
400-419		1	1
420-439			
440-459			
460-479	2	1	3
480-499	1	1	2
500-549	2	2	4
550-599	1	2	3
600-649	5	1	6
650-699	3	1	4
700-749	1		1
750-799	2		2
>800	2	2	4
Number			80
Maximum weight (pounds)	863	1,061	

Tetrapturus angustirostris Tanaka

Shortnose Spearfish

Fūraikajiki (Japan); Indian Spearfish (Hawaii)

Distinguishing characteristics

This little spearfish is characterized by a snout that extends only slightly beyond the lower jaw, a long, slender, compressed body, the greatest depth of which is less than 13 percent of the fork length, relatively short pectoral fins that are less than 14 percent of the fork length, and an easily visible, single lateral line. It lacks the stripes of most of the other species.

Unfortunately, we lack data on a sufficient number of specimens of less than 30 pounds of the other species to separate them clearly from *Tetrapturus*. In very small *Makaira ampla* the snout is scarcely longer than the mandible, but the body is heavier, rounder, and the middle of the first dorsal fin is probably less than two-thirds of the height of the anterior lobe. In small *M. audax*, the middle of the first dorsal fin approaches the height of the anterior lobe as it does in *Tetrapturus*, but *audax* may be distinguished by the presence of stripes and a snout markedly longer than the mandible. We have seen no very small specimens of *Istiompax marlina*, but presumably they may be distinguished unequivocally by the stiff pectoral fin, which in *Tetrapturus* is flexible.

The close resemblance of the shortnose spearfish to the young of the other marlins has led some to suspect (LaMonte and Marcy 1941:21) that it is merely a juvenile form. This view, however, was effectively disproved by the work of Nakamura (1937) who figured the eggs, ovaries, and testes and described one ripe female taken in November which was 152 cm. in fork length and 27 pounds in weight. This fish was taken along with several others with enlarged ovaries. A female with running-ripe ovaries (specimen No. 5 in appendix table 1-A, p. 541) that we captured on March 18, 1954, was 164 cm. fork length. It was not weighed but the weights of other specimens of similar length suggest that its weight should have been about 40 pounds. Such sizes are far below the sizes at which the other species commonly occur and appear to mature.

Jordan and Evermann (1926) listed four Pacific and one Indian Ocean species of this genus, but it

appears probable that there is but a single species in this whole area. Two of the species, *ectenoides* and *brevirostris*, obviously do not belong to the genus *Tetrapturus*. Two other species, *illingworthi* and *kraussi*, were described as new from Hawaii and were separated from the Japanese species *angustirostris* because the latter was described as having a dorsal lobe longer than the pectoral. In the 9 specimens from the central Pacific on which we have these measurements we find 8 in which the dorsal lobe is very slightly longer than the pectoral, and 1 (from Hawaii) in which the opposite is true but the variation in these two characters is such that this comparison of fins is not a good specific character. These authors also distinguished *illingworthi* and *kraussi* on the basis of the separation of the dorsal fins—a character we find highly variable in our specimens. We, therefore, place both species in synonymy with *angustirostris*.

There appears to be no valid reason to retain the genus *Pseudohistiophorus* as proposed by De Buen (1950:170–171). He established this genus because the previous attempts to place heterogeneous species in *Tetrapturus* suggested to him that *Tetrapturus* was the synonym of *Makaira*. We cannot accept this view because the redescription of *Tetrapturus belone* Rafinesque given by Cuvier and Valenciennes (1831:205—the earliest description available to us) is excellent and obviously represents a species extremely close to, if not identical with, our Pacific species.

If *Tetrapturus* should prove to be monotypic, the species name *belone* described from a Mediterranean specimen would have priority. Jordan and Evermann (1926) separated it on the basis of the short, stiff spines in the interspace between the dorsal and anal fins. We have seen none of these spines in the Pacific form, but in some specimens of *M. ampla* we have noticed that the first dorsal fin may continue almost to the second dorsal or may be broken up into separate spines, sometimes even in separate fin slots. This appears to be a matter of individual variation, and further examination of the species from several areas is needed to determine whether this is a constant character.

Color

Immediately after death *T. angustirostris* is a brilliant, deep metallic blue on the back and first dorsal with silvery gray on the sides and white on the belly. In about an hour this rapidly fades

to a dark, slate gray on the back and to black on the first dorsal. We have seen no evidence of stripes and, according to Nakamura (1949), it never has them.

Distribution in the Pacific

According to Nakamura (1951), this pelagic species does not enter coastal or enclosed seas. Off Japan it occurs south of 35° N. latitude and rather densely in the waters east of Formosa and the Philippines from November to January. Nowhere is it abundant enough to be of importance to the fishery. In our POFI fishing we have taken only the 8 specimens recorded in appendix table 1-A; their distribution is indicated in figure 23. In the Hawaiian fishery it is one of the miscellaneous spearfishes that comprises only a small fraction of the total spearfish catch.

On the first six Japanese mothership expeditions to the vicinity of the Caroline Islands (Ego and Otsu, 1952) it was combined with the sailfin in the statistics, and on each of these trips the catch of the two species together averaged only from .02 to .07 per 100 hooks.

Size

This is the smallest of the spearfishes and, according to Nakamura (1949), attains a weight of only 44 pounds, but the POFI specimens which we have weighed from the central Pacific ranged from 18 to 51 pounds. Based on the data obtained from the Honolulu market by the Hawaiian Division of Fish and Game (table 3), the maximum weight found in 177 specimens was 114 pounds. However, the modal size was approximately 38 pounds.

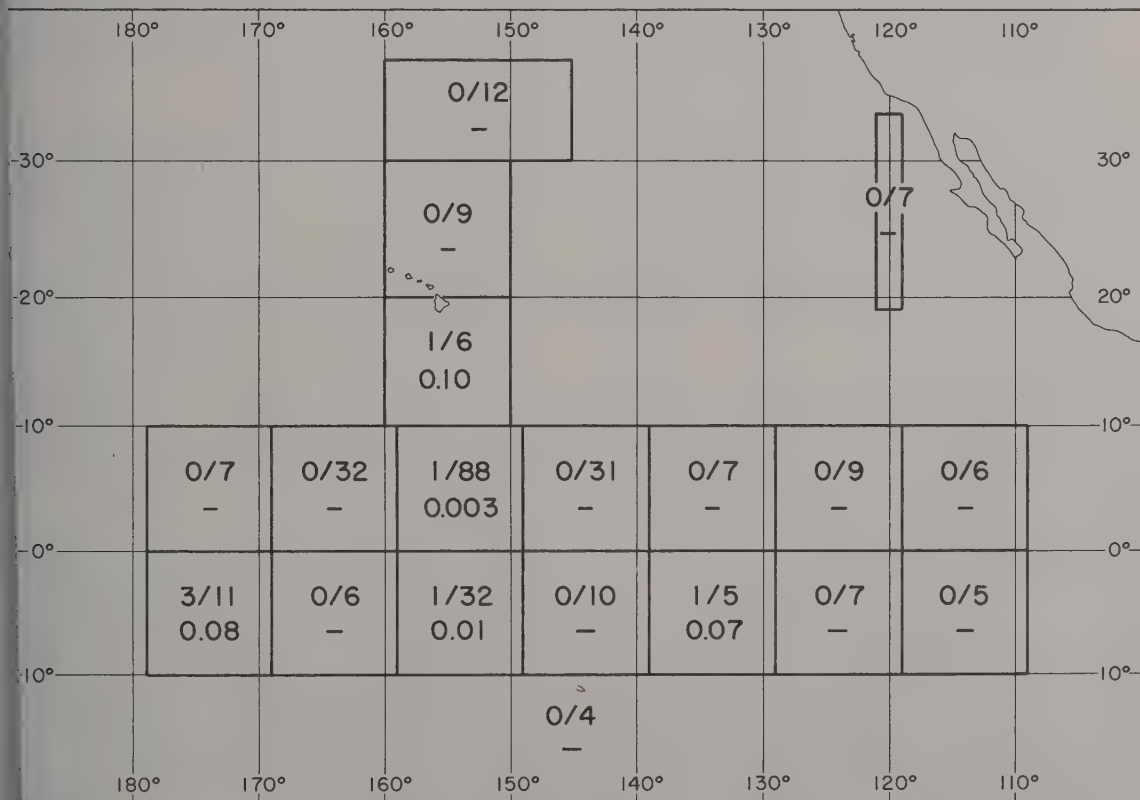


FIGURE 23.—Distribution of POFI catches of shortnose spearfish, *Tetraodon angustirostris*. Fractions indicate stations at which catches were reported out of the total fished; decimals indicate average catch per 100 hooks per day.

TABLE 3.—Weight frequency of shortnose spearfish, *Tetrapturus angustirostris*, from the Honolulu market in 1951

[Data collected by the Hawaiian Division of Fish and Game]

Weight group (pounds)	Number of fish	Weight group (pounds)	Number of fish
15-19.....		70-74.....	6
20-24.....	6	75-79.....	4
25-29.....	11	80-84.....	2
30-34.....	23	85-89.....	1
35-39.....	32	90-94.....	
40-44.....	25	95-99.....	
45-49.....	23	>100.....	2
50-54.....	10		
55-59.....	14	Number.....	177
60-64.....	15	Maximum weight.....	
65-69.....	3	(pounds).....	114

Food

We have notes on the contents of 6 stomachs of which 2 were empty and the other 4 contained squid. Three stomachs contained fish of which only bramids were identified.

Synonymy and references

Tetrapturus angustirostris, Tanaka, 1914:324 (Japan); Nakamura, 1937 (Formosa); Nakamura, 1938:24 (Formosa); LaMonte and Macey, 1941:2 (Japan); Nakamura, 1942 (Formosa); Hirasaka and Nakamura, 1947:11 (Formosa); Nakamura, 1949:56 (Japan); Rosa, 1950:159 (Japan); Nakamura, 1951:35 (northwestern Pacific).

Tetrapturus illingworthi, Jordan and Evermann, 1926:32, pl. 8 (Hawaii); LaMonte and Macey, 1941:2; Brock, 1950 (Hawaii); Rosa, 1950:161 (Hawaii).

Tetrapturus kraussi, Jordan and Evermann, 1926:33, pl. 9 (Hawaii).

Tetrapturus brevisrostris, De Beaufort and Chapman, 1951:238 (850-mm. specimen); Fowler, 1928:136 (Hawaii).

Not *Histiophorus brevisrostris*, Playfair and Günther, 1866:53, 145 (Indian Ocean).

Not *Tetrapturus eclenes*, Jordan and Evermann, 1926:34, pl. 11, fig. 2 (Hawaii).

Istiophorus orientalis (Temminck and Schlegel)

Sailfish

Bashōkajiki (Japan)

Distinguishing characteristics

This genus is effectively distinguished from all other spearfishes by its very high first dorsal fin. It also has a slenderer, more greatly compressed body and much longer pelvic fins.

Problems of identification arise within the genus because so many species have been described.

Those listed by Jordan and Evermann (1926) are differentiated mostly on the basis of the interspace between the dorsal fins, whether or not that space has spines, the shape of the first dorsal, the color, the length of the pectoral, the length of the spear, or the relative size of the second dorsal and second anal fins. We have seen only a few sailfish, but most of these characters are so variable in the other spearfishes that they have little value for identifying species.

There seems little doubt that the species occurring in the central Pacific should be *orientalis*, which most authors have used. On the basis of a cast in the Bishop Museum,⁷ Jordan and Ball, in Jordan and Evermann (1926), also describe *eriquius* from Hawaii in which the first dorsal fin is subtruncated behind with only 34 dorsal spines. The photo in Jordan and Evermann (p. 101) suggests that the posterior part of the dorsal fin was missing from the cast. Further, there are no reports from Hawaiian fishermen of two species of sailfish. We, therefore, regard *eriquius* as a synonym of *orientalis*.

Distribution in the Pacific

Nakamura (1949) gave the distribution of the sailfish as extending from the northeastern coast of Japan south and noted that it is comparatively abundant in the Kinan Sea area. He also stated that this species often enters coastal waters. It is, however, widespread in the tropical Pacific. It was taken in small quantities by the Japanese mothership expeditions near the Caroline Islands in 1951 and 1952 (Ego and Otsu, 1952), and 20 specimens were taken during the POFI longline fishing, as indicated in figure 24. Some of the POFI specimens were taken many hundreds of miles from the nearest land.

Spawning

Spawning sailfish were taken on July 10 and 12 off Hainan Island, according to Nakamura (1940), along with several juveniles of less than 10 mm. He also reported that a spawning female caught on the hook was followed by a companion fish, presumably a male. He (1949) noted that they spawn in Formosan waters from April to August. We can add nothing to the information on spawning because none of the POFI specimens examined had ripening gonads.

⁷ Not included in the current list of specimens in the museum.

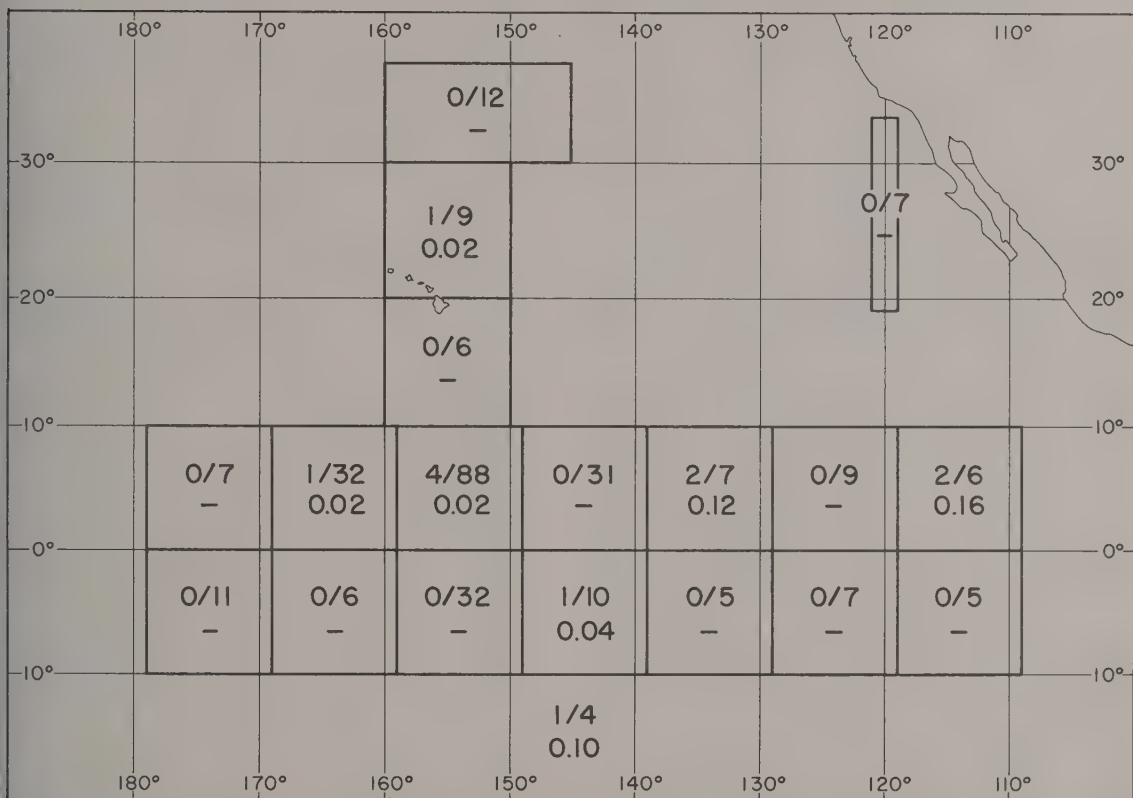


FIGURE 24.—Distribution of POFI catches of sailfish, *Istiophorus orientalis*. Fractions indicate stations at which catches were reported out of the total fished; decimals indicate average catch per 100 hooks per day.

Size

Specimens which we have weighed in the POFI catches ranged from 26 to 106 pounds. Weights of 11 Honolulu market specimens recorded in July and August 1950 by the Hawaiian Division of Fish and Game ranged from 25 to 114 pounds with all but 1 weighing less than 45 pounds. Nakamura (1949) stated that sailfish attain a weight of 132 pounds.

Food

Probably these fish are broadly carnivorous like the other spearfishes but perhaps it is significant that 8 of the 9 stomachs examined contained squid, which usually was the predominant food. The other food items included octopus, nautilus, *Alepisaurus*, one bramid, and one pilot fish.

Synonymy and references

Istiophorus (Histiophorus) orientalis, Temminck and Schlegel, in Siebold, 1844:103, pl. 55 (Japan); Jordan and Evermann, 1926:46, pl. 15, fig. 1 (Japan); Fowler, 1928:136 (Hawaii); Nakamura, 1938:25 (Formosa); Nakamura, 1940 (South China Sea); LaMonte and Marcy, 1941:2 (Hawaii, Japan); Nakamura, 1942 (Formosa); Hirasaka and Nakamura 1947:12, pl. 1, fig. 2 (Formosa); Fowler, 1949:74 (Tahiti); Nakamura, 1949:58 (from northeastern Japan south); Brock, 1950:146 (Hawaii); Rosa, 1950:151 (western Pacific from Indonesia to Vladivostok, Hawaii); De Beaufort and Chapman, 1951:241 (Singapore, Java, Japan, Siam, Hawaii); Yabe, 1953 (Japan); Murphy and Otsu, 1954 (Caroline Islands).

Istiophorus eriquius, Jordan and Ball, in Jordan and Evermann, 1926:48, pl. 15, fig. 2.

Istiophorus brookei, Fowler, 1934:400 (Tahiti).

Bashōkajiki, sailfish, Nakamura, 1944b.

Istiompax marlina (Jordan and Hill)

Black Marlin

Shirokajiki "White Marlin" (Japan); Silver Marlin (Hawaii)

Distinguishing characteristics

Nakamura (1938) has described the anatomical differences between *marlina* on the one hand and *Makaira audax* and *M. ampla* on the other, which differences were subsequently used by Hirasaka and Nakamura (1947) to propose the genus *Marlina*. The principal differences are that (1) the shoulder girdle in *marlina* is considerably broader than in the other species, and the articulation with the pectoral fin restricts its movement; (2) the pelvic girdle in *marlina* has the two sides fused together and difficult to separate, whereas in the other two species the two sides of the girdle are separated by a broad space and they can be easily separated; and (3) the air bladder in *marlina* consists of several layers of small chambers, whereas it has only a single layer of chambers in *ampla* and *audax*.

We believe the differences noted here warrant the retention of *marlina* in a separate genus; however, the generic name *Marlina* cannot be applied to this genus. In the first place, its use is prevented by Zane Grey's introduction of the name *Marlina mitsukurii* in 1928. Since he used the name solely in this combination and prior to 1928 when such a proposal was permitted, *mitsukurii* is the haplotype of *Marlina* Grey. In the second place, Whitley (1931:18) proposed the genus *Istiompax* for *I. australis*, new species, recognized as a synonym of *Makaira marlina* Jordan and Hill. Therefore, the generic name *Istiompax* has precedence over *Marlina* Hirasaka and Nakamura (*non* Grey).

The most distinctive external characters of *marlina*, in addition to the rigid pectoral, are the short ventral fins which range in length from 18 to 31 cm., with an average of 26 in our specimens, and the very low first dorsal, which in its anterior lobe averages about 60 percent of the greatest body depth, but may range from 50 to 80 percent. Many other subtle differences aid in recognizing *marlina* at a glance. The body seems compressed more than in *ampla*, and it appears markedly heavier in the pectoral region than

either *audax* or *ampla* because of the larger hump on the back. Although *marlina* has been reported by Nakamura to differ from *ampla* by having a single, simple lateral line, the lateral line is a poor field character because it is difficult to see in fresh specimens.

Marlina and *ampla* are the only marlins that appear to surpass 1,000 pounds in weight. When near this size, *marlina* is readily distinguishable because the lower jaw from tip to corner of the mouth is at least half the length of the snout from tip to orbit. In *ampla* the lower jaw recedes with growth, and in very large specimens the snout has the appearance of being much longer and more slender than in *marlina*.

The name *marlina* may lack priority if adequate descriptions of marlins from the type localities of *Tetrapturus herscheli* Gray (South Africa), or *Histiophorus brevirostris* Playfair (Zanzibar) become available. Gray's (1838) description of *herscheli* agrees well with *marlina* in most characters. In sizes estimated from his figure (pl. X) the relation of the height of the anterior lobe of the first dorsal to the fork length (13 percent), the height of the first anal to the height of the first dorsal (77 percent), the length of the ventral fins (23 cm.), all agree with our measurements of *marlina*. The height of the 20th ray of the first dorsal (9 cm.) is slightly greater in *herscheli* than *marlina* but the difference is not unreasonable if we assume that the fin slot in *herscheli* may have shrunk during preservation. The relation of the height of the first dorsal to body depth in *herscheli* is not like *marlina*, but the drawing is from a stuffed specimen which may have been distorted. Playfair's (1866) description of *brevirostris* could also have been taken from a slender *marlina*. The height of first dorsal, color, and length of pelvic fin, all fit *marlina* but the body depth is comparable to that of *audax*. We do not suggest changing the name *marlina*, however, until better evidence is available.

Color

The name "white marlin," a literal translation of the Japanese, shirokajiki, probably arises from the appearance of the fish—sometimes a milky white when freshly hooked. We have been amazed at the whiteness of some of these huge fish as they swam near the boat before they had fought hard on the line. When near death and immediately after death the milkiness is replaced by shades of

metallic bluish gray (hence the name silver) ranging from deep color on the back to almost white on the belly. Usually at this time there is smooth gradation in color from the back to the belly, though in a few specimens a sharp line separates side and belly color. A few hours after death the color of the back deepens to a dark lead gray, when it is reasonable to call these fish black marlins.

In Japanese, Hawaiian, and central equatorial Pacific waters the absence of stripes usually distinguishes *marlina* from *audax* and *ampla*, but Nakamura (1938) stated that stripes may sometimes be detected after death and complete removal of the slime. We have seen only one specimen with faint stripes immediately after death. Whitley (1954) described a stiff-finned marlin that had pale blue bars when first caught, and J. E. Morrow, in a personal communication, stated that *marlina* are commonly striped in Peruvian waters when alive. We suspect that the stripes and the white color in life may be more noticeable among the smaller sizes.

Distribution in the Pacific

In the literature reviewed by Rosa (1950), *marlina* has been reported in the eastern Pacific from California to Peru, in New Zealand, Australia, Hawaii, and Tahiti. Nakamura (1949) reports that it occurs widely in the warm seas of the Pacific and Indian Oceans and north off the coast of Japan to about 41° N. latitude. No verification has been obtained for rumors of the occurrence of "black marlin" in California, though both *marlina* and *ampla* appear to occur occasionally off western Mexico (Carl L. Hubbs and Robert L. Wisner, personal communication).

In certain of these peripheral areas *marlina* is apparently one of the abundant marlins, certainly in the sport-fishing centers off Peru, New Zealand, and Australia. Nakamura (1951) believes that the center of its distribution is in the extreme western Pacific and in the adjacent waters of the South China Sea, Sulu Sea, and Celebes Sea. He (1942) calls it the most abundant marlin off Formosa and (1951) reported the catch by species in Formosa for 1943 which, in numbers of fish taken, ranks sailfish, *marlina*, *ampla*, and *audax* in decreasing order. He (1951) also reported that *marlina* is the most abundant spearfish off Okinawa. Off Hawaii and in the equatorial Pacific from south of Baja California to the

Caroline Islands it is much less abundant than *ampla*. The scattered POFI catches (fig. 25) occurred mostly in the vicinity of the Line Islands and north of the Marquesas, but nowhere was *marlina* numerous. In the Hawaiian fishery *marlina* is so scarce that Otsu (1954) lumped it in the catch data with sailfish, shortnose spearfish, and broadbill swordfish, which together comprised less than a tenth of the total spearfish landings in an average year. The nine Japanese mothership expeditions to the vicinity of the Caroline Islands in 1950 and 1951 (Van Campen 1952) had a combined catch rate of less than .01 fish per 100 hooks for *marlina*, which may be contrasted with the catch rate of .53 for *ampla*. Despite this general scarcity, *marlina* has been taken in sufficient numbers in the open Pacific to establish the strong probability that its distribution is continuous from America to Asia but that the concentrations are peripheral off the coasts of the Americas, Asia, and Australia.

The intervening distances, together with anatomical evidence, suggest that these concentrations may be isolated enough for local varieties to be evolving. A difference in color between *marlina* from the central Pacific and from Peruvian areas has been noted. Furthermore, the difference in head length, length of pelvic, and height of the anterior lobe of the first dorsal is somewhat greater between samples of *marlina* than between samples of the other species. Indeed, the overlap in the height of the anterior lobe of the first dorsal (fig. 17) between the samples of *marlina* from Hawaii, New Zealand, and Australia is beyond the commonly accepted level of subspecific differentiation. However, the samples are small and a sample from the equatorial Pacific is intermediate in this dimension, so we shall consider the differences as merely varietal.

Size

This is one of the largest species of bony fishes. Nakamura (1949) stated that *marlina* attains a body length of 350 cm. and a weight of 570 kg. (1,250 lb.). The world's record angling catch taken off Peru on August 4, 1953, weighed 1,560 pounds (Farrington 1953). The previous record, 1,352 pounds, was caught only 6 days earlier. Farrington also reports that the first 25 "black marlin" caught by angling off Peru averaged 817 pounds with many weighing more than 1,000 pounds. It apparently reaches similar sizes off

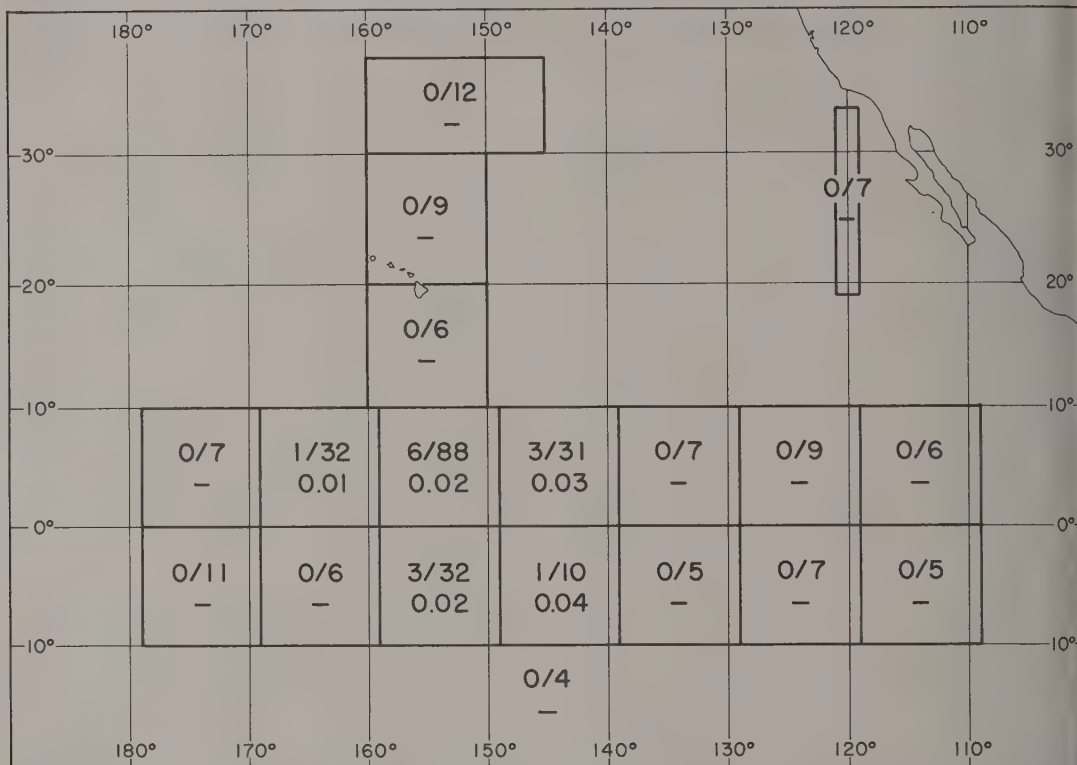


FIGURE 25.—Distribution of POFI catches of black marlin, *Istiompax marlina*. Fractions indicate stations at which catches were reported out of the total fished; decimals indicate average catch per 100 hooks per day.

Australia where one weighing 1,226 pounds was stranded in April 1938, according to Gregory and Conrad (1939), and also off Hawaii where the largest of 77 weighed in the market was 1,100 pounds (table 4).

Such record fish are always females; the largest males have been much smaller. Nakamura (1951) reports a maximum weight for the males of 287 pounds. The largest male in the POFI collection of six in which the sex was determined was 270 pounds and in those reported by Gregory and Conrad from off New Zealand and Australia was 322 pounds.

Data on the size composition of a large catch are given for the Formosan fishery by Nakamura (1944a). He reports that in the 1943 landings at Takao, only 104 *marlina* of 2,542 weighed were more than 440 pounds and the modal size was 90 to 110 pounds. At Suō, of 4,448 weighed, 74 were more than 440 pounds; and there was a broad

TABLE 4.—Weight frequency of *Istiompax marlina* landed at Hawaiian markets in 1950 and 1951

[Data from the Hawaiian Division of Fish and Game]

Weight group (pounds)	Total	Weight group (pounds)	Total
60-79	5	440-459	1
80-99	5	460-479	1
100-119	7	480-499	1
120-139	11	500-549	1
140-159	12	550-599	1
160-179	5	600-649	1
180-199	5	650-699	1
200-219	4	700-749	1
220-239	1	750-799	1
240-259	2	800-849	1
260-279	1	850-899	1
280-299	1	900-949	1
300-319	1	950-999	1
320-339	2	>1,000	1
340-359	3		
360-379	1	Number	
380-399	3	Maximum weight (pounds)	1,100
400-419	1		
420-439	1		

mode at 110 to 200 pounds with a secondary mode at 250 to 270 pounds, in February and March. At Takao, the largest percentage of *marlina*

weighing less than 110 pounds was landed in October and November. In the Hawaiian market data (table 4) one modal group from 100 to 150 pounds occurs, but too few data are available to show other modes.

Food

No specific food studies of *marlina* have appeared but Nakamura (1949) in his general discussion of the food of marlins indicates that they feed on live food but will take dead bait or artificial lures and do not seek food on the bottom. June (1951) has recorded the gluttony of one specimen which contained a 158-pound bigeye tuna.⁸ Of our 10 specimens on which we have food notes, 3 contained remains of the sunfish, *Mola*, and 2 contained tunas, 1 a 30-cm. *Katsuwonus* (1 lb.), and 1 a 94-cm. *Germo* (40 lb.). Another contained vertebrae and fin rays which were evidently from a fairly large fish, since the vertebrae were 5 cm. long in the centrum and the fin rays were about 20 cm. in length. This marlin probably as broadly carnivorous as the other species of marlins which eat a great variety of fish and squid. Certainly, if they can capture tunas and other animals would be fast enough to escape them.

Spawning

Nakamura (1949) stated that he had no concrete data on the spawning habits of *marlina* but speculated from some data on the condition of the gonads and the relative abundance of males and females that it spawns off Formosa around August-October. None of the POFI specimens had opening gonads.

Seasonal occurrence

The season for *marlina* in Formosa is from October through April, according to Nakamura (1938, table 9; 1951, table 43) who gave catch statistics for the Suō fish market. Off Cabo Blanco, Peru, the sport fishermen have taken it throughout the year, according to a personal communication from

J. E. Morrow. Apparently, there has not been enough fishing in the other parts of the Pacific where *marlina* is plentiful to clearly establish the best seasons.

Synonymy and references

- Makaira marlina*, Jordan and Hill, in Jordan and Evermann, 1926:59, pl. 17 (Pacific coast of Mexico); Grey, 1928:47 (New Zealand); Walford, 1937:48 (Baja California, Pacific coast of Panama); Nakamura, 1938:29 (Formosa); Nakamura, 1942 (Formosa); Farrington, 1949:151 (New Zealand, Australia, Pacific coast of Panama and Mexico); Brock, 1950:146 (Hawaii); June, 1951:287 (Hawaii); Nakamura, 1951:37 (western Pacific); Murphy and Otsu, 1954 (Caroline Islands).
Marlina marlina, Hirasaka and Nakamura, 1947:15, pl. 3, fig. 1 (Formosa); Nakamura, 1949:63 (western Pacific, Indian Ocean).
Makaira ampla marlina, Nichols and LaMonte, 1941:8, fig. 1 (west coast of the Americas, New Zealand, Australia); LaMonte and Marcy, 1941:2 (Peru, New Zealand, Australia, Hawaii, west coast of Mexico, California).
Makaira nigricans marlina, Nichols and LaMonte, 1935b:328; Gregory and Conrad, 1939:443 (New Zealand, Australia); Gabrielson and LaMonte, 1950:27 (Australia, New Zealand, Tahiti, Peru, Pacific coast of Panama and Mexico); Rosa, 1950:143 (California to Peru, New Zealand, Australia, Tahiti); Morrow, 1954:819 (East Africa).
Makaira ampla tahitiensis, Nichols and LaMonte, 1941:8, fig. 3 (Tahiti, Hawaii); LaMonte and Marcy, 1941:2 (Tahiti, Hawaii).
Makaira nigricans tahitiensis, Nichols and LaMonte, 1935a:1, fig. 1 (Tahiti); Nichols and LaMonte, 1935b:328; Gabrielson and LaMonte, 1950:28 (Tahiti, Hawaii, Pacific coast of Mexico); 1950:144 (Pacific coast of Mexico, Hawaii, Tahiti).
Makaira mazara, LaMonte, 1955:336, pl. 9 (in part).
Makaira mazara tahitiensis, LaMonte, 1955:342, pl. 10 (in part).
Istiompax australis, Whitley, 1931:18 (Australia).
Istiompax dombraini, Whitley, 1954:60 (Australia); 1955:295 and fig. 293.
Histiophorus gladius, Ramsay, 1881:295 (Australia).
Makaira australis, Fowler, 1934:400, 402 (Australia, Tahiti).
Makaira indica, Fowler, 1949:74 (Hawaii, Galapagos, Tahiti).
Shirokajiki, white marlin, Nakamura, 1944a (Formosa); Van Campen, 1952:7 (Caroline Islands).
Black marlin, Farrington, 1953 (Chile, Peru, Ecuador, Pacific coast of Panama and Mexico).
Silver marlin, Farrington, 1949:152 (Hawaii, Tahiti) (in part).

Probable synonyms

- Tetrapturus herscheli*, Gray, 1838:313, pl. X (South Africa).
Histiophorus brevirostris, Playfair and Günther, 1866:53, 145 (Zanzibar); Day, 1878:199, fig. 3, pl. 47 (India).
Tetrapturus brevirostris, Rosa, 1950:160 (South Africa, Zanzibar, India, Indo-Pacific area); De Beaufort and

⁸After this manuscript was written, two similar records were obtained. Ralph E. King of the POFI staff reported that on April 4, 1955, a *marlina* 158 cm. fork length was taken on a longline at 1°49' N. latitude and 157°38' W. longitude. It contained a yellowfin tuna 154 cm. fork length which was estimated from length-weight curves to weigh 157 pounds. The *marlina* apparently had taken the dead herring bait after eating the tuna because the tuna showed no signs of being hooked nor did it have bait in its stomach. The *marlina* was hooked normally in the jaw. The tuna had two holes through its body similar in size to the marlin's spear. E. S. Iversen, formerly of the POFI staff, reported that a *marlina* 303 cm. fork length was taken on April 8, 1955, at 4°31' N. latitude and 160°30' W. longitude, that contained a yellowfin tuna 154 cm. fork length which was estimated to weigh 70 pounds.

Chapman, 1951:238 (Java, Zanzibar, Seychelles, Muscat, coast of New South Wales, Hawaii), 3,900-mm. specimen.

Makaira herscheli, Smith, 1950:315, fig. 875 (South Africa); Rosa, 1950:139 (South Africa); Smith, 1956a:26, pls. 1 and 2 (South Africa).

The *Tetrapturus australis*, Anon., in Whitley, 1955:292.

Makaira audax (Philippi)

Striped Marlin

Makajiki "True Marlin" or Akakajiki "Red Marlin" (Japan)

Distinguishing characteristics

This marlin in the familiar sizes of 100 to 200 pounds is readily distinguishable from either *marlina* or *ampla* by its higher first dorsal fin and slenderer, more compressed body. The first dorsal is higher in the anterior lobe, where its height is usually more than the greatest body depth, as well as in the middle where the rays range from 8 to 15 cm. with an average length of 10 cm. The vertical bars on the sides, which are probably always present and usually prominent, provide the obvious vernacular name.

The considerable allometric growth, however, has led to the confusion of very large and very small specimens with other species. The very large specimens tend to become thicker and broader through the pectoral region and the height of the anterior lobe of the first dorsal may be as little as 90 percent of the greatest body depth. They may closely resemble the slenderer specimens of *ampla* which sometimes have prominent stripes. This has caused anglers in Hawaii and perhaps elsewhere to identify 400- to 700-pound specimens of *ampla* as *audax*.

Among the very small *audax*, the high middle dorsal fin has led to the description of the species *formosana* and *grammatica*, and even of *Tetrapturus ectenes*. The pronounced negative growth of the mid-dorsal fin as shown in figure 7 provides evidence that these high-finned forms are merely young *audax*, and not a distinct species. All those we have seen can be separated from *Tetrapturus* by the stripes and the snout which is about twice as long as the mandible. Occasionally, however, the high median dorsal rays are retained in medium-sized adults off California and off

Mexico (Carl L. Hubbs and Robert L. Wisner, personal communication).

Color

Audax is generally deep metallic blue above with white belly and prominent vertical stripes on the sides when captured. The blues fade after death and in a few hours the predominant color is a dark blue gray or lead gray broken by faded but persistent stripes. The number of stripes in POFI specimens varied from 10 to 21, but frequently the count was uncertain because of the tendency for alternate stripes to be faint.

The Japanese name akakajiki "red marlin" arises from the pink flesh, according to Nakamura (1951), who stated that it is especially valued for sashimi, or raw fish, because of its fine appearance and flavor. In the specimens from equatorial waters we have noticed that some are pink fleshed, others are not. We have no explanation for the difference.

Distribution in the Pacific

The striped marlin has been taken by the Japanese longline fleet (Ueyanagi 1954b) almost everywhere they have fished. This includes the equatorial waters, east from Borneo to about 155° W. longitude, along the coasts of Java and Sumatra in the Indian Ocean, off northeastern New Guinea, along the coast of Asia north to the East China Sea and along the outer coast of Japan north as far as 44° N. latitude. In addition, POFI vessels have taken it through most of the equatorial area east to 110° W. longitude and north of Hawaii to nearly 35° N. latitude (fig. 26). It has previously been reported off the coast of the Americas from southern California to northern Chile and off New Zealand and Australia (Rosa 1950).

The concentrations suggest that *audax* prefer the more temperate waters, however. The best grounds for the Japanese longline fleet have been sketched by Ueyanagi (1954b) who showed two areas east of Formosa roughly between 20° and 30° N. latitude, one of them from 128° to 135° E. longitude, the other from 140° to 170° E. longitude. Both of these areas are best from March to June. A little later in the season from August to November the best grounds are east of Japan roughly from 34° to 40° N. latitude, 145° to 175° E. longitude. Other, lesser concentrations are located immediately off the coast of Japan, just

south of Korea, in the Celebes Sea, and at times in the South China Sea. *Audax* is regularly taken but not abundantly in the winter albacore fishery east of Japan from about 28° to 35° N. latitude. It is scarce along the Pacific Equator near the Carolines and the Marshall Islands where the Japanese mothership expeditions took *audax* at an average rate of less than .01 per 100 hooks (Van Campen 1952). It is a little more abundant to the east of 150° W. longitude where POFI catches averaged as high as .30 per 100 hooks (fig. 26).

The relation of the marlins to the ocean currents was discussed by Nakamura (1954a). He noted that in the principal marlin grounds in the western Pacific between 14° and 30° N. latitude, most of the *audax* are caught north of the region of sub-tropical convergence, whereas to the south *ampla* predominates. There is not, however, a complete separation of the species.

Off Hawaii, *audax* is the most abundant marlin. Otsu (1954) showed that the average monthly landings for the years 1948 to 1952 contained more *audax* from December through June and more *ampla* from July through November. The average annual landings by weight of *audax* were a little less than *ampla*, but *audax* averaged only about 70 pounds compared with 200 to 300 for *ampla* (tables 5 and 6), so the numbers of *audax* landed were much the greater.

Food

In the other species of marlins, the scattered observations suggest that they are broadly carnivorous, but in *audax* the specific food studies show it clearly. Morrow (1952b) examined 53 stomachs taken off New Zealand and found the principal food items to be *Scomberesox* and *Arripis*. Hubbs and Wisner (1953), who examined 32 stomachs from marlin caught near San Diego, Calif., in 1951, found the principal food items to

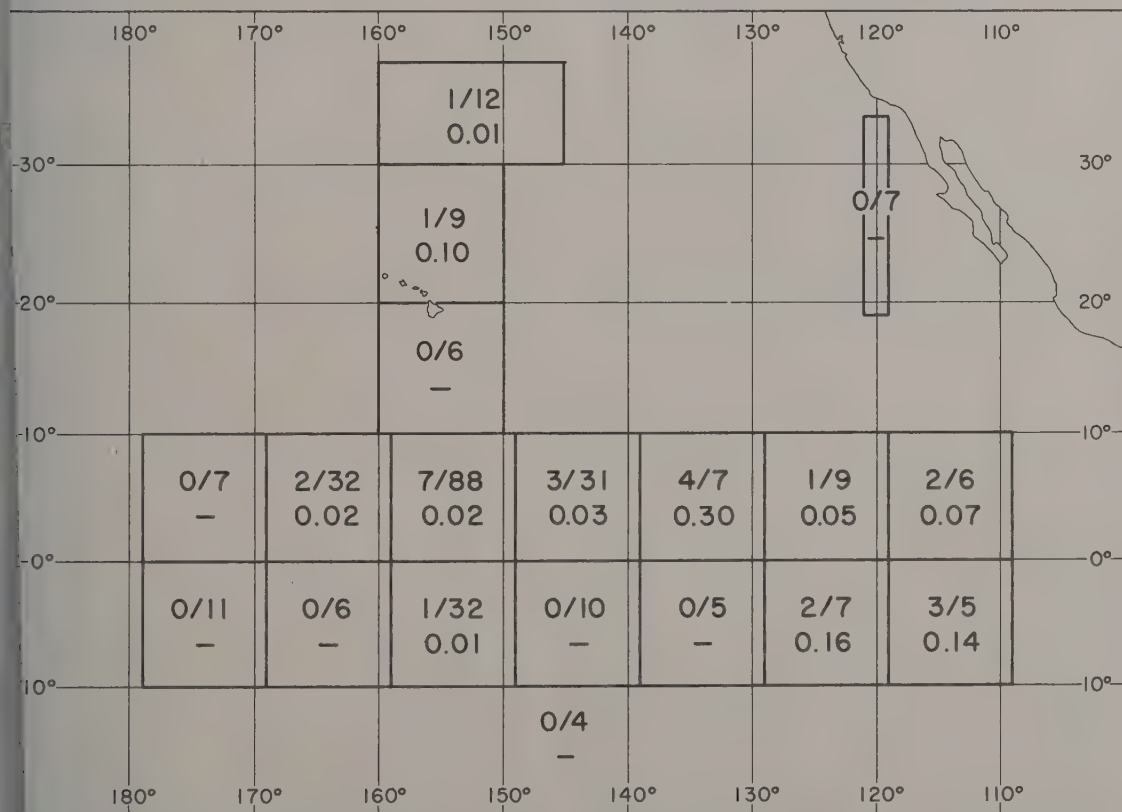


FIGURE 26.—Distribution of POFI catches of striped marlin, *Makaira audax*. Fractions indicate stations at which catches were reported out of the total fished; decimals indicate average catch per 100 hooks per day.

be the saury, *Cololabis*, and the northern anchovy, *Engraulis*. In both of these studies minor quantities of cephalopods were found. Yabuta (1953), who reported on 64 striped marlin taken off the Bonin Islands, gives a long list of items which includes *Gempylus* in 75 percent of the stomachs, *Pseudoscophelus* in 41 percent, *Alepisaurus* in 41 percent, *Ostracion* in 30 percent, crustacea in 30 percent, and cephalopods in 67 percent of the stomachs. Among the numerous minor food items were *Katsuwonus*, 14 percent, and even the broadbill swordfish *Xiphias gladius* in 1 stomach. Of the 19 stomachs from equatorial waters taken by POFI (appendix table 5, p. 554), 13 contained material which included several tunalike fishes, some identifiable as *Auris*, and miscellaneous remains of other fish, shrimp, and squid.

Size

The maximum size of the striped marlin is a matter of some uncertainty because it seems to have been confused with *ampla*. Farrington (1949) noted that the world's record, taken off California, was 692 pounds; the next largest, taken off Chile, weighed 483 pounds. He states, "It seems strange that no one has ever taken a striped marlin between these weights." The larger record seems to us unreasonably large when compared with the maxima found in other parts of the Pacific. Griffin (1927) reports a male (?) of 381 pounds from off New Zealand, and Grey (1928) caught 21 off New Zealand that ranged up to 350 pounds. Gregory and Conrad (1939) took 27 off New

Zealand and Australia weighing up to 336 pounds, and Morrow (1952a) presented the data on 48 fish weighing up to 336 pounds.

In the North Pacific, the striped marlin seems to reach an even smaller maximum size. Nakamura (1944b) in a weight frequency study of 1,387 specimens from off Formosa had class sizes ranging up to 130 kg. (290 pounds), although in his 1949 paper he reported that this marlin reached a maximum of 220 pounds. The latter weight seems improbably low, because in the specimens taken along the Pacific Equator by POFI one of 314 pounds was weighed, and in the Hawaiian market (table 5) occasional specimens weighing nearly 300 pounds and one rather questionable record of 434 pounds have been listed. Ueyanagi (1954b) gives a maximum class size of 200 cm. orbit to fork, which is approximately 190 pounds. The largest specimen caught in 1955 off La Jolla, Calif., weighed 406.5 pounds (Carl L. Hubbs and Robert L. Wisner, personal communication). All of this information suggests that the maximum size of the striped marlin is less than 500 pounds.

In the longline fishery off Japan, the modal size of *audax* is rarely greater than 100 pounds, according to Ueyanagi (1954a). He also showed the variation in size composition by latitude from the Equator to 30° N. In each latitudinal zone there is a major mode around 75 to 80 pounds, but between 10° and 20° N. another major mode is centered at 105 cm., or 24 pounds. Such a

TABLE 5.—Weight frequency of striped marlin, *Makaira audax*, from the Honolulu market, January 1949–February 1952

[Data from the Hawaiian Division of Fish and Game]

Weight group (pounds)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Year 1949:												
10-19				3	1					11	40	
20-29	22	48	4	5	8		3		1	1	24	14
30-39	113	615	94	24	38	54	16		2	5	9	2
40-49	27	146	136	134	65	21	7	2		4	6	1
50-59	3	27	28	180	152	10	2	4	2	12	13	
60-69	5	28	14	32	33	8	1	2	5	29	26	1
70-79	17	90	40	14	10	7	3	1	4	32	46	6
80-89	36	157	84	21	4	19	3		1	32	54	5
90-99	24	141	78	47	28	44	21	1	2	20	20	5
100-109	10	89	102	52	28	69	26		1	12	14	2
110-119	10	24	37	36	27	49	16		1	10	8	1
120-129	1	13	10	17	27	23	7	1		5	5	
130-139		2	10	13	15	17	4	1	1	4	6	
140-149		3	2	6	11	6	1		1	3	1	
150-159		3	4	7	11	5	2					
160-169		1	2	5	8	3	1		1	2		
170-179			1	2	4							
180-189				2	3	3	2	2			1	
190-199				2	2					1		
>200			1	3	5	3		1		1	2	
Number	268	1,387	647	605	480	351	116	16	22	186	276	41
Maximum weight (pounds)			308	235	227	227		203		215	205	43

TABLE 5.—Weight frequency of striped marlin, *Makaira audax*, from the Honolulu market, January 1949–February 1952—Continued

[Data from the Hawaiian Division of Fish and Game]

Weight group (pounds)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Year 1950:												
10-19		2	4			4				2	10	5
20-29	45	70	21	2	18	56	10	3	1	4	97	22
30-39	34	186	228	25	31	63	42	15	2	4	10	50
40-49	11	10	217	74	22	9	12	17	2	3	5	1
50-59	6		46	45	13	6		6		5	7	4
60-69	13	28	37	17	15	20	2	2	3	25	30	28
70-79	30	88	105	34	15	34	8	1	13	51	82	102
80-89	32	149	138	73	44	126	28	4	7	50	138	172
90-99	31	123	125	99	67	188	49	1	2	33	141	160
100-109	35	69	77	53	62	137	37	3	4	14	88	107
110-119	8	30	36	21	29	101	28	3		15	53	61
120-129	6	11	11	17	15	47	21			4	17	30
130-139	4	4	8	6	14	13	9	3		2	9	8
140-149	1	5	3	3	12	14	2	2			2	4
150-159				4	5	6	1			1	2	3
160-169		1	1	2	6	7						
170-179			1	1	2	2	1		1			
180-189				2	2	2	3			1		
190-199					2	1			1			
>200		1		1	1	1	3	2		1		
Number	256	858	1,058	479	375	837	256	62	36	215	691	757
Maximum weight (pounds)		310		297	239	211	229	226		233		
Year 1951:												
10-19		1								1	3	
20-29	6	5		1	8	2	1			6	6	4
30-39	10	7	59	17	8	15	6	1	1	1	3	8
40-49	4	6	94	42	6	5	5	1	1	1	3	1
50-59		3	22	32	10	5	6	3	3	3	4	
60-69	4	13	10	7	6	3	2	9	1	7	13	8
70-79	16	30	46	15	19	8	5	6	3	16	29	28
80-89	31	51	88	52	59	34	7	3	3	11	37	27
90-99	24	61	102	51	71	77	17	3	3	15	29	25
100-109	17	34	63	43	83	122	26	3	3	9	12	9
110-119	9	15	32	23	42	78	14	2	1	6	6	6
120-129	4	10	10	14	58	44	7			2	11	1
130-139	1	3	5	7	37	21	12	3	1	9	1	6
140-149			4	3	18	22	4	1		1	3	2
150-159		2	1	10	19	6	1			2		1
160-169			1	5	7	6					2	
170-179			1	1	4	4						2
180-189			1	1	2	1		1				
190-199			1	2	1	1				1	1	
>200				1	3	1	1	1		3	1	1
Number	126	241	539	329	461	454	114	34	17	93	161	129
Maximum weight (pounds)				200	216	231	210	219		304	226	214
Year 1952:												
10-19		7	1									
20-29												
30-39	22	13										
40-49	10	15										
50-59	1	6										
60-69	6	10										
70-79	19	53										
80-89	30	84										
90-99	23	45										
100-109	10	25										
110-119	5	6										
120-129	1	1										
130-139	2	2										
140-149	1	1										
150-159	1	3										
160-169	1	1										
170-179												
180-189												
190-199												
>200												
Number	138	266										
Maximum weight (pounds)												

itudinal distribution appears to exist in the central Pacific, for the POFI catches in the territorial area included only a few striped marlin less than 100 pounds, whereas in the Honolulu

market (table 5) about half of the fish weighed less than 60 pounds each. In the latter case, the distribution is very definitely and characteristically bimodal in most months of the year. In the

winter months, the position of the modes corresponds quite closely to those given by Ueyanagi for the 10° to 20° latitudinal zone.

If we follow the progression of the modes from month to month in table 5, two rather striking things may be noted. First, after the period of low catches in August and September, the fishery resumes on striped marlin of very different weight composition than existed in early summer. Secondly, between about November and April the smaller mode progresses with reasonable smoothness from about 30 to 50 pounds, and from about October to July the larger mode progresses, again with reasonable smoothness, from about 80 to 105 pounds. If we assume that the fishery has been fishing the same stock of fish through these months it would appear that such a progression might be due to growth and, hence, an annual increment of about 30 pounds can be estimated.

Spawning

In the South China Sea near Formosa, spawning seems to be at its peak from April to May according to Nakamura (1949). He also stated that *audax* is known to spawn near the Ogasawara Islands around May and June.

That spawning occurs at this season is suggested by the scanty POFI observations from the central equatorial Pacific. Two males with milt in the testes were taken during March, and two females with enlarged ovaries were taken in February and March.

Synonymy and references

Histiophorus audax, Philippi, 1887:35-38, pl. 8, figs. 2 and 3 (Chile).

Istiophorus audax, Fowler, 1944:499 (Tarapacá, Iquique, Valdivia).

Marlina audax, Smith, 1956a:30 (South Africa).

Makaira audax, Smith, 1956b:758 (South Africa).

Tetrapturus mitsukurii, Jordan and Snyder, 1901:303, pl. 16, fig. 5 (Japan); Fowler, 1928:136 (Hawaii, tropical Pacific).

Makaira mitsukurii, Jordan and Evermann, 1926:61, pl. 18 (Japan, Hawaii, California); Griffin, 1927:143, pl. 14 (New Zealand); Walford, 1937:47 (California, Pacific coast of Mexico); Nakamura, 1938:27 (Formosa); Gregory and Conrad, 1939:443 (New Zealand, Australia); Nichols and LaMonte, 1941:8, fig. 2; LaMonte and Macey, 1941:2 (Japan, Hawaii, California, Chile, New Zealand, Australia); Nakamura, 1942 (Formosa); Farrington, 1949:150 (Chile, Peru, Ecuador, Pacific coast of Panama and Mexico, California, Hawaii, New Zealand, Australia, Marianas, Japan); Brock, 1950:147 (Hawaii); Gabrielson and LaMonte, 1950:28 (California, west coast of Mexico

and Panama, Ecuador, Peru, Chile [S. to Caldera, Australia, New Zealand, Hawaii]; Rosa, 1950:13 (Americas from California to Caldera, Chile, New Zealand, Australia, Philippines, Japan, Hawaii); Nakamura, 1951:36 (warm seas of western Pacific); Morrow, 1952a:53 (New Zealand); Morrow, 1952b:14 (New Zealand); Murphy and Otsu, 1954 (Carolin Islands); Morrow, 1954:819 (East Africa); LaMonte, 1955:333, pl. 7, pl. 8 (2), and 346, pl. 12 (2) thought to be a young one.

Marlina mitsukurii, Grey, 1928:47 (New Zealand).

Makaira grammatica, Jordan and Evermann, 1926:56, pl. 16 (Hawaii).

Makaira hoi, Jordan and Evermann, 1926:63, pl. 19, fig. 1 (Pacific coast of Mexico).

Makaira zelandica, Jordan and Evermann, 1926:65, pl. 19, fig. 2 (New Zealand).

Tetrapturus ectenes, Jordan and Evermann, 1926:34, pl. 11, fig. 2 (Hawaii).

Kajikia mitsukurii, Hirasaka and Nakamura, 1947:1, pl. 2, fig. 1 (Formosa); Nakamura, 1949:60 (south from northeastern Honshu, Japan); Nakamura, Yabuta, and Ueyanagi, 1953 (Japan); Ueyanagi, 1954a (northwestern Pacific from Equator to 4° N.); Ueyanagi, 1954b (Western Pacific from Japan to Australia, Indian Ocean off Sumatra).

Kajikia formosana, Hirasaka and Nakamura, 1947:1 (Formosa); Nakamura, 1949:61 (Philippine Sea, Japan).

Kajiki, *makajiki*, *akakajiki*, striped marlin, Nakamura, 1944b (Formosa); Van Campen, 1952 (Carolin Islands); Yabuta, 1953 (Bonin Islands); Nakamura, 1954b (northwestern Pacific, 14° to 30° N. latitude); Farrington, 1953 (Chile, Peru, Ecuador, Pacific coast of Mexico, California, Hawaii, New Zealand, Australia).

Probable synonym

Istiophorus ludibundus, Whitley, 1933:83 (New South Wales).

Makaira ampla (Poey)

Blue Marlin

Black Marlin (Hawaii); Kurokajiki (Japan)

Distinguishing characteristics

This is the giant marlin with the flexible pectoral fin that can be folded flat against the body, with the more nearly cylindrical body and, in very large sizes, with the relatively long snout. There is less of a hump on the back than in *marlina*, more than in *audax*. The anterior lobe of the first dorsal is higher than in *marlina*, but lower than in *audax*. The anterior lobe of the first anal fin, on the contrary, is higher in *ampla* than in either *audax* or *marlina* and the relation between the first an-

and first dorsal is the best character we have found for distinguishing *ampla* from *audax*. In *ampla*, the height of the first anal averaged 86 percent of the height of the first dorsal with a range of 76 to 100 percent; in *audax*, the range was from 50 to 76 percent with an average of 66 percent. The center of the first dorsal fin is low and in our specimens there is a suggestion of an actual decrease in the average length of the 20th ray with the growth of the fish up to 200 cm.; but in the specimens of more than 200 cm. fork length the length of the 20th ray is nearly constant. The average length of the ray in *ampla* is approximately 6 cm. with the range in our specimens from 2 to 9 cm.; in *audax*, which has a similar growth pattern, the range is from 8 to 14 cm. with an average of 10 cm. The length of the pelvic fin is comparable to that of *audax* and longer than that of *marlina*, averaging about 34 cm. in our specimens with no change in size according to length of fish.

This species appears to be unique among the marlins in the growth relation of mandible and snout (fig. 13).⁹ In *audax* and *marlina* the snout and mandible grow approximately isometrically, whereas in *ampla* the mandibular growth definitely negatively allometric. As a result the snout appears long in very large individuals.

The lumping of the Atlantic and Pacific forms of this marlin in the single species *ampla* will no doubt be contested by people who automatically consider that such geographic separation indicates distinct species. However, in none of the characters considered in the preceding pages do we find a difference that even approaches the subspecific level. Until morphological differences can be found it seems preferable to consider both forms as belonging to the same species.

Color

In the living specimens of *ampla* that we have seen in the Pacific, the predominant color of the upper parts is a brilliant, deep metallic blue which fades rapidly after death to a lead-gray color mixed with browns wherever the fish has been rubbed or scraped. Stripes usually are present on the sides immediately after death but are rarely conspicuous, and generally some are so faint that

it is difficult to count them. They may be absent or remain conspicuous after death and cannot be relied on to distinguish the fish from either *marlina* or *audax*.

Distribution in the Pacific

This is the predominant marlin of the central tropical Pacific, having been taken in all of the tropical areas fished by POFI, from 110° W. longitude to 180° longitude, with catch rates up to 0.35 per 100 hooks (fig. 27). West, along the Equator in the Marshall and Caroline Islands area, the Japanese mothership expeditions of 1950 and 1951 found it even more abundant, for they had an average catch rate of 0.53 per 100 hooks. Off Formosa it is taken in lesser quantities than *marlina* and *orientalis* (Nakamura 1951, table 114). Northward from the Equator its abundance declines with latitude and, according to Nakamura (1951, fig. 31), for the zone from 143° to 150° E. longitude just off the coast of Japan *ampla* becomes less abundant than *audax* at about 15° N. latitude, but moderate quantities are caught as far north as 40°. It has been reported recently off Australia by Whitley (1954). LaMonte (in Gabrielson and LaMonte 1950, p. 515) showed a photograph of a black marlin from off Acapulco which almost certainly is of this species because the fin is folded against the side, and the body shape, height of first dorsal, and the very short mandible are typical of *ampla*.

The localities where *ampla* has been taken by the Japanese longline fishery are shown in the atlas prepared by the Nankai Regional Research Laboratory (Yabuta 1954). Catches are reported from the South China Sea off Hainan Island, from the Celebes Sea just east of the Philippines off northern New Guinea, and then almost continuously along the Equator east to 155° W. longitude. The best catches were made during the summer months at 10° to 15° N. latitude north of the Caroline Islands. A few were taken during winter months in the albacore fishery along 30° N. latitude, east of Japan as far as 175° W. longitude, north of Midway. They also were taken at fishing stations in December and January in the Indian Ocean along the coasts of Java, Sumatra, and in the vicinity of the Nicobar Islands. Special concentrations were found during February 1952 off northwest Australia at about 15° S. latitude, 118° E. longitude, and in the vicinity of the Solomon Islands. In the Hawaiian longline fishery, *ampla*

⁹Dr. Hiroshi Nakamura, in a personal communication, pointed out that allometric growth of the snout occurs in *Istiophorus orientalis*. At about 200 cm. the snout is extraordinarily long in relation to body length and, as the fish grows, the length of snout in relation to body length decreases.

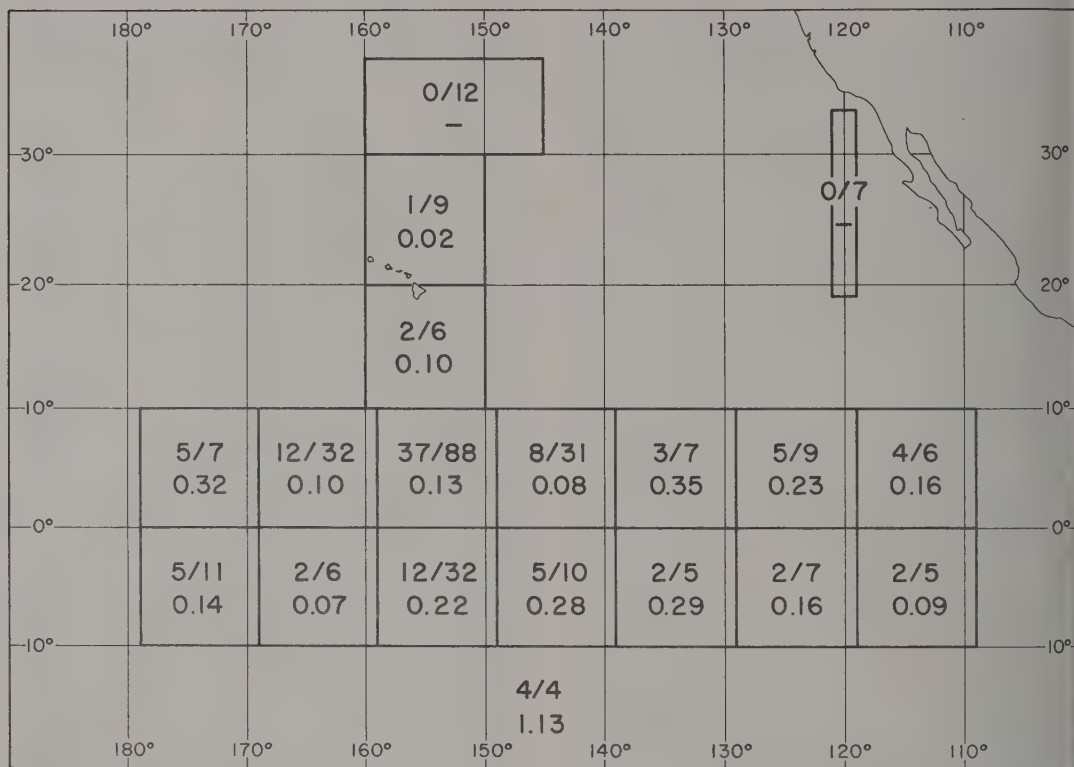


FIGURE 27.—Distribution of POFI catches of the blue marlin, *Makaira ampla*. Fractions indicate stations at which catches were reported out of the total fished; decimals indicate average catch per 100 hooks per day.

is the most abundant spearfish by weight, and the annual landings ranged from a low of 512,000 pounds to a high of 679,000 pounds during the period 1948 to 1952 (Otsu 1954).

Food

All reports indicate that this species is broadly carnivorous on fish and cephalopods of the open ocean. Nakamura (1942) tabulated the food contents of 163 stomachs from fish taken in the east Philippine Sea. Of these, 53 stomachs contained squid, 11 *Leiognathus*, 12 *Balistes*, 11 *Auris*, and lesser amounts of some 9 other genera of fish. One contained a species of shrimp. In the POFI catches, 36 stomachs contained food, of which 34 contained fish and 16 cephalopods. The commonest fishes in the stomachs were the tunalike fishes, particularly *Katsuwonus* in the larger individuals. Most of the cephalopods were squid. In two additional stomachs from POFI catches

the complete contents were not noted but specimens of *Xiphias gladius* were preserved for later examination (see p. 519).

Seasonal occurrence

Yabuta (1954) presented data which show that the catch rate varies little throughout the year in the tropical seas in the vicinity of the Caroline and Marshall Islands. Murphy and Otsu (1954) note that the catches of *ampla* by the nine Japanese mother-ship expeditions in this same area showed minor peak in February and another in October 1951, but that the catch rate during the summer months of 1951 was only about half that during the summer months of 1950.

North of the Carolines, however, there is evidence of a seasonal migration and the peak abundance which occurs in May at 12° to 16° N. latitude, moves farther north with the season until the peak is at 24° to 28° N. in September. Farther east

off the Marshall Islands the principal fishery is from 8° to 12° N., and here the seasonal abundance gradually increases until July, then slowly declines. Off Formosa, Nakamura (1942) reported that *ampla* is plentiful on the Pacific side during the summer, and he (1949) stated that they are extremely rare in the Kuroshio Current region from October to April. Off Hawaii, Otsu (1954) showed that *ampla* reaches the peak of abundance and is the principal spearfish in the catch from July through November, whereas during the other months of the year *audax* is the principal species in terms of pounds landed. Thus, north of the equatorial area the seasonal occurrence suggests a summer movement of *ampla* northward followed by a return south in the late autumn.

ize

The reports from the Japanese and Hawaiian fisheries indicate that *ampla* rivals and may even surpass *marlina* in maximum size reached. Nakamura

(1949) reported that *ampla* attains 1,100 pounds, but a weight of 1,450 pounds has been recorded from the Hawaiian fishery (table 6), and fishermen recall weighing specimens of more than 1,600 pounds.¹⁰ The POFI specimens include one of 1,002 pounds from Hawaii and another nearly as large from the equatorial area, which was partly eaten by sharks (Nos. 67 and 68 in appendix table 1-E, p. 548).

As in *marlina*, the large *ampla* are always females. The largest male weighed by POFI was 218 pounds. Ueyanagi (1953) and Nakamura et al. (1953) both reported that males do not exceed 200 cm. (orbit to fork), which is equivalent to about 255 pounds. Yabuta (1954), in the atlas of Japanese longline fishing, summarized data on size composition by sex of *ampla* from several areas and all length frequencies showed a mode at about

¹⁰ The maximum sizes of *ampla* attained in the Pacific are much greater than reported from the Atlantic where the angling record is 742 pounds (official 1955 list of the International Game Fish Association).

TABLE 6.—Weight frequency of blue marlin, *Makaira ampla*, from the Honolulu market, January 1949–February 1952

[Data collected by the Hawaiian Division of Fish and Game]

Weight group (pounds)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mar 1949:												
10-19							1					
20-29							1					
30-39							1					
40-49							1					
50-59							1					
60-69							1					
70-79		1					1					
80-89							1					
90-99							1					
100-109							1					
110-119							1					
120-129							1					
130-139	2	4	1	1	1	3	10	17	7			
140-149		5	4	1	6	6	16	32	10	9	2	2
150-159	1	2	4	1	5	5	11	22	13	10	2	1
160-169		1	3	6	4	7	8	21	19	13	4	3
170-179	1	3	1	1	2	4	8	26	14	10	3	1
180-189	1	2	2	3	5	2	2	19	8	3	5	
190-199		2	3	6	2	2	3	14	13	6	2	
200-219		3	1	3	3	5	10	12	7	9	2	2
220-239		3	7	5	1	5	3	6	1	7	6	3
240-259		3	4	10	5	5	1	4	1	3	3	1
260-279		3	8	1	5		1			5	6	2
280-299		2	8	5	4	4	2	4	8	8	5	4
300-319		2	5	9	6	3	2	4	4	9	3	4
320-339			3	5	5	3	1	5	2	4	9	3
340-359				4	6	6	3	2	3	2	4	3
360-379				3	4	4	3	6	1	2	5	4
380-399				3	7	6	3	2	4	4	7	1
400-419				2	3	1	4	4	6	4	2	4
420-439				2	2	3	4	5	2	1	3	4
440-459				3	3	3	1	3	7	5	1	2
460-479				2	1	3	4	2	8	2	3	1
480-499				1	4	1	2	5	5		2	1
500-549				3	2	7	2	6	9	8	7	4
550-599				2	1	4	3	2	5	11	3	
600-649				1	1	2	2	1	6	5	2	1
650-699				1	1			2	3	2		
700-749				1		1	1	4	2	2		
750-799					1			1	1	1	1	
800-849				1		1			1	1	1	
850-899				1		1			1	1	1	
900-949												
950-999												
>1,000						1						1
Number	6	56	88	102	93	85	142	270	168	173	89	59
Maximum weight (pounds)					1,015							1,011

TABLE 6.—Weight frequency of blue marlin, *Makaira ampla*, from the Honolulu market, January 1949–February 1952—Con

[Data collected by the Hawaiian Division of Fish and Game]

Weight group (pounds)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Year 1950:												
10-19.												
20-29.				2			1					
30-39.										1		
40-49.				2							2	
50-59.				1			1			2	1	
60-69.											1	
70-79.									1		5	
80-89.									1		4	
90-99.		1				1	1		1		5	
100-109.							3	4			4	
110-119.						2	1	6	4		4	
120-129.						1	7	9	7		2	
130-139.	1	1	1			5	2	19	15	7	8	
140-149.			3	1	2	3	15	24	32	25	11	
150-159.				1			13	21	47	38	13	
160-169.				1	1	3	13	14	26	28	9	
170-179.	1	2	2	2	2	1	7	25	31	25	11	
180-189.		1				1	5	20	16	28	5	
190-199.	1	1			1	4	5	10	18	15	5	
200-219.	4	2	2		1	3	7	15	12	20	12	
220-239.	1		1	3	1		1	9	9	5	4	
240-259.		1	2			2	3	5	8		5	
260-279.	1	5	1	2	2	1	3	5	9	4		
280-299.	1	2	2	3	1	4	2	2	1	7	6	
300-319.	1	1	1	6	3		1	2	3	8	2	
320-339.	2	2	1	2	3	2	1	2	6	4	3	
340-359.	2	1	2	1	1		7	1	3	3	3	
360-379.		3	1	2	1			3	3	3	6	
380-399.	1	2	4			2	3	3	3	4	1	
400-419.	1	2	4	3	3		5	4	5	3		
420-439.	2	1	4	3	3	2	3	5	7	2	1	
440-459.		1			2	3		4	7	5	3	
460-479.	1		2	3	1		2	5	7	3	2	
480-499.			1	4	2	2	2	2	8	3	3	
500-549.		2	1	4	5		2	13	14	8	6	
550-599.	2			2				2	7		1	
600-649.			1	1		4	3	4	5	3		
650-699.		2	1	1	1		1	3	3		2	
700-749.		1			3		1	1	3	2	1	
750-799.		1		1	1		2	1			2	
800-849.									1			
850-899.			1						1			
900-949.							1		2			
950-999.		1					1			1		
>1,000.			1		1		1	1	1	2	1	
Number.	26	39	42	51	46	50	123	251	323	304	164	
Maximum weight (pounds).			1,002		1,030			1,056	1,001	1,058	1,287	
Year 1951:												
10-19.												
20-29.												
30-39.												
40-49.												
50-59.												
60-69.												
70-79.												
80-89.					1		1			2	3	
90-99.										4		
100-109.				1					3	4	3	
110-119.							3	6	5	5		
120-129.		1				2	8	24	18	15	4	
130-139.	2			1	1		16	39	29	17	8	
140-149.		1		2			13	34	37	40	14	
150-159.					3	5	5	31	30	46	17	
160-169.	1	1			1	3	6	24	35	27	20	
170-179.				1	1	2	8	20	15	24	15	
180-189.			1	1	1	2	17	17	8	11	11	
190-199.					3	1	6	6	4	17		
200-219.		2		1	1	2	5	7	5	10	5	
220-239.			2			2	6	7	4	8		
240-259.		1		4	3	6	2	3	7	8		
260-279.			4		5	3	5	8	1	8		
280-299.		2	2	1	7	1	2	9	5	4	14	
300-319.		4	2	2	3	7	3	7	1	4	6	
320-339.	1	3	2	2	2	3	2	5	6	3	7	
340-359.	1	3	2	1	5	1	6	7	7	3	7	
360-379.			1		4	1	3	6	9	8	4	
380-399.	1	2	2		4	3	4	9	4	9	10	
400-419.	2	2	3	4	5	6	3	5	3	4	5	
420-439.				1	3			11	6	6	1	
440-459.		2	4	1	4	2	4	10	6	14	8	
460-479.				2	3	1	3	4	9	5	2	
480-499.		2	3		2	1	1	11	7	5		
500-549.				10	8	6	10	23	16	19	5	
550-599.	1	1	1	1	5	4	7	10	7	8	8	
600-649.			3	3	8	4	5	15	8	3	1	
650-699.		2		1	1	2	3	9	5	2	1	
700-749.			2			1	5	5	1	3		

TABLE 6.—Weight frequency of blue marlin, *Makaira ampla*, from the Honolulu market, January 1949–February 1952—Con.

[Data collected by the Hawaiian Division of Fish and Game]

Weight group (pounds)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
ear 1951—Continued												
750–799			1		1	2	2	4	1		2	
800–849			2		1	1	4	1	1	2		
850–899		1		2			1	2				
900–949						1	1	3				
950–999									1			
>1,000			2	1			2					
Number	9	31	47	41	91	89	161	389	345	362	224	71
Maximum weight (pounds)			1,450	1,052			1,107		1,090			
ear 1952:												
10–19												
20–29												
30–39												
40–49												
50–59												
60–69												
70–79		1										
80–89												
90–99		1										
100–109		1										
110–119			1									
120–129		1										
130–139												
140–149												
150–159			1									
160–169												
170–179												
180–189		1										
190–199												
200–219		1										
220–239		1										
240–259		2	2									
260–279			1									
280–299		1	2									
300–319												
320–339			3									
340–359			2									
360–379			4									
380–399			1									
400–419												
420–439			1									
440–459			1									
460–479		1										
480–499												
500–549			2									
550–599												
600–649			1									
650–699												
700–749			1									
750–799												
800–849												
850–899												
900–949												
950–999												
>1,000			1									
Number	11	24										
Maximum weight (pounds)		1,003										

10 cm. (125 lb.) with most of the males ranging from 140 cm. (85 lb.) to 180 cm. (175 lb.).

The *ampla* of less than about 200 pounds, which one of the Japanese authors consider to be mostly males (Ueyanagi 1953; Nakamura et al., 1953; Iwata 1954), appear in the fishery in quantity only during the summer months. This is thought to indicate a segregation by sex during migrations. A similar phenomenon exists in Hawaii (table 6), where the catch of *ampla* from July to October contains a large modal group from 130 to 220 pounds which may be males. There is also at this

time some increase in the catch of larger fish, but not nearly as great an increase as in the modal group.

Spawning

Among the *ampla* specimens examined from the POFI catches, we found no ripe females but did find males with freely flowing milt in the gonads from February through October (and captured only three between November and January). So it is likely that at least some of the males may be ready to spawn at almost any time of the year in the equatorial Pacific.

Nakamura (1942) thought that, like the rest of the spearfishes, *ampla* spawns over long periods of time in wide areas of ocean, and he suspected that the great increase in the proportion of males in the catch off Formosa during May is indicative of the spawning season. He also stated (1951) that *ampla* spawns east of Luzon from May to July.

Synonymy and references

No attempt has been made to include a comprehensive list of references to the Atlantic form.

- Tetrapturus amplus*, Poey, 1860: 243, tab. 15, fig. 2, (Cuba).
Tetrapturus mazara, Jordan and Snyder, 1901:305 (Japan); Fowler, 1934:400 (Japan, Hawaii).
Makaira mazara, Jordan and Evermann, 1926:53, pl. 11, fig. 2 (Japan, Hawaii); Griffin, 1927:141, pl. 13 (New Zealand); Nakamura, 1938:28 (Formosa); Nakamura, 1941 (Philippine Sea); Nakamura, 1942 (Formosa); Brock, 1950:146 (Hawaii); Nakamura, 1951:37 (northern tropical Pacific); Murphy and Otsu, 1954 (Caroline Islands); LaMonte, 1955:336 (in part).
Makaira nigricans ampla, Conrad and LaMonte, 1937:207 (Bahamas); Shapiro, 1938 (Bahamas); Gregory and Conrad, 1939, pl. V (Bahamas); Gabrielson and LaMonte, 1950:29; Rosa, 1950:145 (north-western Atlantic, Caribbean Sea to New England).
Makaira ampla, LaMonte, 1955:344.
Makaira ampla mazara, LaMonte and Marcy, 1941:2 (Japan); Nichols and LaMonte, 1941:8 (Japan).
Makaira nigricans mazara, Rosa, 1950:141 (Pacific coast of Mexico, California, Hawaii, Japan, Australia, New Zealand).
Makaira ampla ampla, LaMonte and Marcy, 1941:2 (Cuba to North Carolina).
Eumakaira nigra, Hirasaka and Nakamura, 1947:16, pl. 2, fig. 2 (Formosa); Nakamura, 1949:65 (warm seas of Pacific and Indian Oceans); Nakamura, Yabuta, and Ueyanagi, 1953 (Japan); Yabuta, 1954 (western Pacific, Japan to Australia and east to Line Islands, Indian Ocean off Sumatra).
Istiompax howardi, Whitley, 1954:58, pl. 3, fig. 3 (Australia).
Acapulco black marlin, Gabrielson and LaMonte, 1950:515 (Pacific coast of Mexico).
Kurokajiki, black marlin, Van Campen, 1952 (Caroline Islands); Yabuta, 1953 (Bonin Islands).
Blue marlin, Farrington, 1937; Farrington, 1949:153 (Cuba to New England, Caribbean Sea).
Silver marlin, Farrington, 1953:160 (Hawaii).

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APPENDIX

Because it is necessary to compare the spear-fishes of the world by means of measurements, our original data and some computations are presented here. The original observations were obtained by members of the POFI scientific staff in addition to their regular observations on tunas. These

members were: Donald K. F. Ching, Thomas S. Hida, Isaac I. Ikehara, Edwin S. Iversen, Joseph E. King, Walter M. Matsumoto, Sueto Murai, Garth I. Murphy, Tamio Otsu, Thomas J. Roseberry, William F. Royce, Richard S. Shomura, Wilvan G. Van Campen, and Henny S. H. Yuen.

APPENDIX TABLE 1-A.—Original data and morphometric measurements of 8 specimens of *Tetrapturus angustirostris*, by POFI

[Measurements in millimeters]

Item	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
Latitude	2°56' N.	7°00' S.	2°57' S.	15°46' N.	9°01' S.	10°00' N.	10°00' N.	15°46' N.
Longitude	150°08' W.	169°59' W.	169°49' W.	154°13' W.	131°24' W.	151°02' W.	151°02' W.	154°13' W.
Date taken	2-17-53	5-28-53	11-21-52	1-26-53	3-18-54	5-3-53	5-3-53	1-26-52
Sex	?	?	Male	?	Female ¹	?	?	Female
Weight (pounds)	24	18	21	33	1,638	(²) 51	(³)	46
Snout to fork tail	1,470	1,509	1,530	1,589	1,537			1,791
Snout to upper tail notch		1,415			346			
Snout to inside 1st dorsal		327			415			
Snout to inside pectoral		387			435			
Snout to inside pelvic		406			438			
Snout to posterior edge opercle	359	387	379	403	404			437
Snout to anterior edge orbit		215			234		225	
Bit diameter	29	38	34	31	33	43		34
Posterior edge orbit to posterior edge opercle		134			141			
Orbit to fork of tail	1,296	1,306			1,428	1,526		1,577
Posterior edge orbit to fork of tail		1,256			1,371	1,463		
Length of mandible		216			225	234	239	
Orbit width opposite tip mandible	9	15		17	17	14		
Orbit depth opposite tip mandible					12			
Depth of head		110			124	124		
Greatest body depth	165	151	161	196	179			217
Fork width at tip pectoral		70			88			
Fork depth at vent					160			
Anal groove to inside of anal		135			140			
Dorsal height longest anterior ray		196	212	225	210	222		233
Dorsal height 20th ray	180	179		172	177	204		171
Dorsal length base	900	898		955	1,017	998		1,067
Dorsal height	45	44		53	50	56		56
Dorsal length base		58			61	59		
Anal height	100	108	128	132	114	134		143
Anal length base		164			215	213		
Total length	180	174	205	197	204	217		214
Pelvic length	308	330	402	353	332	351		366
Anal spread		490			490	503		
Space 1st and 2d dorsals	23	33		15	0	87		48
Space 1st and 2d anals	81	114			100	123		
Total fin folds against side	Yes	Yes		Yes	Yes	Yes		
Number stripes on sides	0			0	0	0		0
Number free spines between dorsals	0	0		0	0	0		

² Shark-eaten.

³ Approximate; broken parts.

Running ripe; ovaries 4 cm. diameter, mature ova about 1 mm. diameter. Snout broken.

APPENDIX TABLE 1-B.—Original data and morphometric measurements of 6 specimens of *Istiophorus orientalis*, by POFF

[Measurements in millimeters]

Item	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Latitude.....	7°39' N.	7°10' N.	9°05' N.	7°20' N.	1°00' S.	8°59' N.
Longitude.....	131°20' W.	152°14' W.	131°40' W.	110°20' W.	140°05' W.	110°09' W.
Date taken.....	11-14-52	10-25-52	11-15-51	3-4-54	3-13-53	3-3-
Sex.....		Female	?	Female	Male	Female
Weight (pounds).....		33		64	77	
Tip snout to fork tail.....	1,530	1,809	2,031	2,232	(1)	2,232
Tip snout to upper tail notch.....				2,090		2,232
Tip snout to inside 1st dorsal.....				666		743
Tip snout to inside pectoral.....				743		787
Tip snout to inside pelvic.....				735		735
Tip snout to posterior edge opercle.....	555	633	699	519		519
Tip snout to anterior edge orbit.....				43	33	43
Orbit diameter.....	30	30	39	167		167
Posterior edge orbit to posterior edge opercle.....				1,727	1,784	2,031
Naris to fork of tail.....	1,142	1,379	1,550	1,664		1,664
Posterior edge orbit to fork of tail.....				288		288
Length of mandible.....						
Sword width opposite tip mandible.....						
Sword depth opposite tip mandible.....						
Depth of head.....				183		183
Greatest body depth.....	187	229	274	293	300	300
Body width at tip pectoral.....				119		119
Body depth at vent.....						
Ventral groove to inside anal.....				88		88
1st dorsal height longest anterior ray.....				393		393
1st dorsal height 20th ray.....				759	825	825
1st dorsal length base.....				1,161	1,173	1,173
2d dorsal height.....			89	81	104	104
2d dorsal length base.....				90		90
1st anal height.....	125	176	173	201	209	209
1st anal length base.....				253		253
Pectoral length.....	200	323	345	338	398	398
Pelvic length.....				581	623	623
Caudal spread.....		678		764		764
Interspace 1st and 2d dorsals.....				13	36	36
Interspace 1st and 2d anals.....				119		119
Pectoral fin folds against side.....				Yes		Yes
Number stripes on sides.....				20	24	24

¹ Snout broken.² Includes estimated 50 mm. for broken snout.³ Longest ray (#19) was 842 cm.⁴ Longest ray (#18) was 777 cm.APPENDIX TABLE 1-C.—Original data and morphometric measurements of 11 specimens of *Istiompax marlina*, by POFF

[Measurements in millimeters]

Item	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Latitude.....	0°03' N.	1°48' S.	2°34' S.	2°13' N.	2°15' N.	4°58' N.
Longitude.....	155°15' W.	139°59' W.	155°23' W.	155°15' W.	151°19' W.	149°57' W.
Date taken.....	12-4-53	3-11-53	8-19-53	4-15-54	10-30-52	5-15-
Sex.....	?	Male	?	Male	Female	Female
Weight (pounds).....	182	183		270		270
Tip snout to fork tail.....	2,379	2,507	2,568	2,716	2,749	2,749
Tip snout to upper tail notch.....	2,309		2,375	2,490		2,490
Tip snout to inside 1st dorsal.....	750		823	858		858
Tip snout to inside pectoral.....	823		920	1,000		1,000
Tip snout to inside pelvic.....	870		970	1,045		1,045
Tip snout to posterior edge opercle.....	825	928	915	981		981
Tip snout to anterior edge orbit.....	530		613	647		647
Orbit diameter.....	51	36	51	57	37	57
Posterior edge orbit to posterior edge opercle.....	244		251	277		277
Naris to fork of tail.....	1,361	1,904	1,983	2,087	2,149	2,149
Posterior edge orbit to fork of tail.....	1,798		1,904	2,012		2,012
Length of mandible.....	343		378	404		404
Sword width opposite tip mandible.....	45	41	34	44		44
Sword depth opposite tip mandible.....				35		35
Depth of head.....	230		210	281		281
Greatest body depth.....				491		491
Body width tip pectoral.....		455		267	505	267
Body depth at vent.....				449		449
Ventral groove to inside anal.....				96		96
1st dorsal height of longest anterior ray.....	284	280	311	280		280
1st dorsal height of 20th ray.....	74	71	60	45		45
1st dorsal length base.....	898	1,153	95	1,216		1,216
2d dorsal height.....	27	86	95	98		98
2d dorsal length base.....	115		123	146		146
1st anal height.....	231	243		281	274	281
1st anal length base.....	250			314		314
Pectoral length.....	413	467	443	481	574	481
Pelvic length.....	232	279	256	136		136
Caudal spread.....	880		908	980		980
Interspace 1st and 2d dorsals.....	278		113	93		93
Interspace 1st and 2d anals.....	130	168		146		146
Pectoral fin folds against side.....	No	No	No	No		No
Number of stripes on sides.....	0	0	0	3		0
Number of free spines between dorsals.....	3(?)	0	0	0		0

See footnotes at end of table.

APPENDIX TABLE 1-C.—Original data and morphometric measurements of 11 specimens of *Istiompax marlina*, by POFI—Con.

Item	No. 7	No. 8	No. 9	No. 10	No. 11
Latitude	3°22' N.	5°20' S.	4°36' N.	0°08' N.	3°52' S.
Longitude	160°24' W.	179°55' W.	154°41' W.	154°51' W.	155°13' W.
Date taken	8-23-53	2-22-52	4-20-54	8-13-53	4-11-54
Sex	?	Female	Female	?	Female
Weight (pounds)	293		418		587
Snout to fork tail	2,842	2,999	3,027	3,214	3,467
Snout to upper tail notch	2,638		2,788		3,210
Snout to inside 1st dorsal	952	975	940		1,124
Snout to inside pectoral	1,005		1,054		1,151
Snout to inside pelvic	1,085	1,145	1,135		1,228
Snout to posterior edge opercle	1,039	1,024	1,080	1,141	1,235
Snout to anterior edge orbit	715		703	743	808
Orbit diameter	52		64	61	63
Posterior edge orbit to posterior edge opercle	272		323	337	364
Ear to fork of tail	2,160		2,353	2,508	2,693
Posterior edge orbit to fork of tail	2,075		2,260	2,410	2,596
Length of mandible	405		440		518
Lower jaw width opposite tip mandible	50		56		61
Lower jaw depth opposite tip mandible			43		51
Depth of head	230		310	277	386
Greatest body depth		568	591		647
Body width tip pectoral			339		355
Body depth at vent.			505		535
Central groove to inside anal			52		194
1st dorsal height of longest anterior ray	308	348	386	387	393
1st dorsal height of 20th ray	72		67	69	72
1st dorsal length base	1,231		1,425	1,316	1,501
1st dorsal length	102		121		
1st dorsal length base	142		148	163	
1st anal height	275		308	297	295
1st anal length base	294		336	367	336
Pectoral length	534	531	566	596	644
Elvial length	304		255	295	255
Audal spread	1,023	1,112	1,120		1,166
Interpace 1st and 2d dorsals	127		66	243	
Interpace 1st and 2d anals	146		150	134	210
Pectoral fin folds against side	No		No	No	No
Number of stripes on sides	0			0	0
Number of free spines between dorsals	0			0	0

1 Excluding stomach contents.

2 Approximate measurement; tip of snout broken.

3 About 12 stripes faintly showing when first caught.

APPENDIX TABLE 1-D.—Original data and morphometric measurements of 25 specimens of *Makaira audax*, by POFI

[Measurements in millimeters]

Item	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9
Latitude	5°58' N.	8°07' N.	5°36' S.	8°07' N.	4°18' N.	2°23' N.	3°23' N.	1°59' S.	3°23' N.
Longitude	161°11' W.	149°57' W.	120°25' W.	149°57' W.	130°11' W.	130°28' W.	130°29' W.	120°03' W.	130°29' W.
Date taken	5-21-54	8-11-52	10-29-52	8-11-52	11-12-52	11-10-52	11-11-52	10-29-52	11-11-52
Sex	?	?	?	?	?	?	?	?	?
Weight (pounds)	21	52		75		86	92		99
Snout to fork tail	1,423	1,869	1,891	1,968	2,036	2,160	2,165	2,282	2,294
Snout to upper tail notch	1,315								
Snout to inside 1st dorsal	495		689	732	712	764	745	801	818
Snout to inside pectoral	547								
Snout to inside pelvic	560		808	833	837	867	868	914	935
Snout to posterior edge opercle	548		740	753			781	829	848
Snout to anterior edge orbit	383								
Orbit diameter	35	36	35	36	36	36	37	36	37
Posterior edge orbit to posterior edge opercle	130								
Ear to fork tail	1,049	1,402	1,417	1,464	1,550	1,649	1,670	1,742	1,720
Posterior edge orbit to fork of tail	1,005								
Length of mandible	219								
Lower jaw width opposite tip mandible	14								
Lower jaw depth opposite tip mandible									
Depth of head	109								
Greatest body depth		259	279	309	293	305	321	338	329
Body width tip pectoral									
Body depth at vent.									
Central groove to inside anal									
1st dorsal height longest anterior ray	232	340	374	354	359	390	405	413	397
1st dorsal height 20th ray	151								
1st dorsal length base	665								
1st dorsal length	55		84		82	97	96	87	94
1st anal height	146	201	254	217	230	243	266	258	262
1st anal length base	200								
Pectoral length	204	330	376	371	387	398	429	434	438
Elvial length	297								
Audal spread	455								
Interpace 1st and 2d dorsals	17								
Interpace 1st and 2d anals	44								
Pectoral fin folds against side	Yes								
Number of stripes on sides	16								
Number of free spines between dorsals									

See footnotes at end of table.

APPENDIX TABLE 1-D.—Original data and morphometric measurements of 25 specimens of *Makaira audax*, by *POFI*—Co

[Measurements in millimeters]

Item	No. 10	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16	No. 17
Latitude	5°15' N.	0°59' S.	8°59' N.	3°19' S.	1°11' N.	1°04' N.	2°34' S.	0°51' N.
Longitude	110°17' W.	111°28' W.	110°09' W.	112°11' W.	130°15' W.	151°05' W.	155°23' W.	158°53' W.
Date taken	8-5-54	3-9-54	3-9-54	3-10-54	11-9-52	2-10-53	6-15-53	6-10
Sex	Male	Female	Male	Female	Female	?	?	?
Weight (pounds)		157	145	205			245	
Tip snout to fork tail	2,443	2,518	2,545	2,548	2,571	2,622	2,736	2,736
Tip snout to upper tail notch		2,333	2,342	2,362			2,500	2,500
Tip snout to inside 1st dorsal		813	798	835	877		909	909
Tip snout to inside pectoral		895	873	923			1,002	1,002
Tip snout to inside pelvic		914	900	964	963		1,025	1,025
Tip snout to posterior edge opercle		878	859	915	884	1,001	1,002	1,002
Tip snout to anterior edge orbit		587	562	605			664	664
Orbit diameter	53	53	53	55	43	42	67	67
Posterior edge orbit to posterior edge opercle		225	244	255			271	271
Naris to fork of tail	1,904	1,959	2,012	1,969	2,019		2,094	2,094
Posterior edge orbit to fork of tail	1,827	1,878	1,930	1,888			2,065	2,065
Length of mandible	361	398	396	418			446	446
Sword width opposite tip mandible	30	29	28	36		32	39	39
Sword depth opposite tip mandible	20	19	18	20				
Depth of head	208	220	222	205			194	194
Greatest body depth	365	365	369	390	387	405		
Body width tip pectoral	195	216	200	260				
Body depth at vent.	265	273	273	336				
Ventral groove to inside anal		88	77	57				
1st dorsal height longest anterior ray	399	436	438	411	461	448	481	481
1st dorsal height 20th ray	86	115	82	109		89	127	127
1st dorsal length base	1,210	1,245		1,237		1,227		1,227
2d dorsal height	91		119	100	103	107	123	123
2d dorsal length base	84		96	93			105	105
1st anal height	241	290	289	277	305	304	263	263
1st anal length base	321	340	268	358			362	362
Pectoral length	448	488	525	463	490	527	535	535
Pelvic length	379	319	387	220		348	361	361
Caudal spread	875	916	962	844			1,045	1,045
Interspace 1st and 2d dorsals	20			49		53		
Interspace 1st and 2d anals	83	105	75	61			72	72
Pectoral fin folds against side	Yes	Yes	Yes	Yes			Yes	Yes
Number stripes on sides	16	21	16			Ca. 15		
Number free spines between dorsals	0	0	0	0		0	0	0

Item	No. 18	No. 19	No. 20	No. 21	No. 22	No. 23	No. 24	No. 25
Latitude	2°39' S.	1°30' S.	6°07' N.	9°57' N.	1°20' N.	5°47' N.	8°39' N.	1°47' N.
Longitude	179°54' E.	169°00' E.	154°47' W.	165°06' W.	155°03' W.	162°06' W.	164°57' W.	158°16' W.
Date taken	2-20-52	3-8-52	4-22-54	7-29-53	2-3-52	1-25-53	7-30-53	6-9
Sex	Female	Female	Female		Female	?		
Weight (pounds)			290				314	314
Tip snout to fork tail	2,757	2,798	2,842	2,889	2,911	2,933	3,039	3,039
Tip snout to upper tail notch							2,792	2,792
Tip snout to inside 1st dorsal	978	1,010	946				969	969
Tip snout to inside pectoral			1,024				1,065	1,065
Tip snout to inside pelvic	1,107	1,154	1,051				1,097	1,097
Tip snout to posterior edge opercle	1,022	1,050	1,027		1,028	1,083	1,071	1,071
Tip snout to anterior edge orbit			655				691	691
Orbit diameter	47	48	67	65		47	67	67
Posterior edge orbit to posterior edge opercle			305				313	313
Naris to fork of tail	2,100	2,115	2,223		2,256	2,247	2,385	2,385
Posterior edge orbit to fork of tail			2,120	2,166			2,281	2,281
Length of mandible			467				473	473
Sword width opposite tip mandible			40			35	36	36
Sword depth opposite tip mandible			22					
Depth of head			280				238	238
Greatest body depth	435	422	490		545	474		
Body width tip pectoral			281					
Body depth at vent.			335					
Ventral groove to inside anal			63					
1st dorsal height longest anterior ray	460	500	450	486	573	486	466	466
1st dorsal height 20th ray			77			110	99	99
1st dorsal length base			1,346			1,288	1,364	1,364
2d dorsal height		121	111			70	136	136
2d dorsal length base			113				117	117
1st anal height	302	327	283			259	238	238
1st anal length base			388				366	366
Pectoral length	549	592	589		522		540	540
Pelvic length			281			416	343	343
Caudal spread			1,075					
Interspace 1st and 2d dorsals			82			163	160	160
Interspace 1st and 2d anals			94			126	165	165
Pectoral fin folds against side			Yes	Yes		Yes	Yes	Yes
Number stripes on sides			16				12	12
Number free spines between dorsals			0			0	1	1

1 Approximate; tip of snout broken.

2 Without viscera.

* 5 intermediate stripes.

APPENDIX TABLE 1-E.—Original data and morphometric measurements of 68 specimens of *Makaira ampla*, by POFI

[Measurements in millimeters]

Item	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
Latitude	5°03' S.	3°26' S.	2°15' S.	5°53' N.	2°56' S.	2°54' N.	4°03' S.	6°47' S.	5°08' S.	8°59' N.
Longitude	150°05' W.	149°55' W.	169°58' W.	161°15' W.	150°08' W.	150°19' W.	179°58' E.	180°	150°05' W.	110°09' W.
Date taken	5-15-53	5-14-53	6-1-53	1-27-53	2-17-53	2-3-53	2-21-52	2-24-52	5-15-53	3-3-54
Sex	Male	Male	Male	Male	Male	Male	Female	Male	Male	Male
Weight (pounds)	28	77	93	90	110				118	136
Snout to fork tail	1,350	1,788	1,824	1,897	1,985	1,989	2,011	2,019	2,086	2,126
Snout to upper tail notch	1,233	1,648	1,673						1,917	1,971
Snout to inside 1st dorsal	338	629	533				659	634	685	641
Snout to inside pectoral	375	597	588						724	707
Snout to inside pelvic	388	604	600				734	736	729	708
Snout to posterior edge of opercle										
Snout to anterior edge orbit	372	574	588	574	677	656	675	670	723	699
Orbit diameter	214	379	383						491	466
Anterior edge orbit to posterior edge opercle	34	47	41	33	37	37	33	40	52	50
Iris to fork of tail	124	148	164						180	183
Anterior edge orbit to fork of tail	1,151	1,438	1,463	1,558	1,560	1,593	1,590	1,599	1,612	1,680
Length of mandible	1,102	1,362	1,400						1,543	1,610
Orbit width opposite tip of mandible	185	227	241						283	274
Orbit depth opposite tip of mandible	16	28	25	28	30	33			31	33
Depth of head		170	147							23
Greatest body depth	117		300	290	328	349	323	321	132	196
Body width tip pectoral	119		199						330	359
Body depth at vent			44						209	230
Anal groove to inside anal	28								40	61
Dorsal height longest anterior ray	171	235	233	225	244	294	260	275	232	245
Dorsal height 20th ray	84	80	71	80	66	63			63	51
Dorsal length base	716	890	887	909	950	1,005			975	1,056
Dorsal height	51	62	65	68	70	68		79	80	85
Dorsal length base	67	74	76						83	288
Anal height	138	189	195	206		247	227	233	241	245
Anal length base	215	286	275						320	335
Pectoral length	187	325	313	332	350	408	369	395	382	377
Pelvic length	310	371	355	352	363	394			300	301
Ventral spread	476	690	684					762	802	758
Space 1st and 2d dorsals	9	23	30	48	37	37			34	20
Space 1st and 2d anals	40	44	38	55					59	58
Dorsal fin folds against side	Yes	Yes	Yes	Yes					Yes	Yes
Number stripes on sides	(1)	12		13					12	15
Number free spines between dorsals	0	0	0	0	0	0			0	0

Item	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16	No. 17	No. 18	No. 19	No. 20
Latitude	5°03' S.	6°47' S.	0°02' N.	1°43' N.	5°41' S.	9°01' S.	3°36' S.	6°40' S.	0°01' N.	1°13' S.
Longitude	150°05' W.	180°	179°48' E.	169°59' W.	169°44' W.	131°24' W.	140°55' W.	169°03' W.	169°02' W.	150°11' W.
Date taken	5-15-53	2-24-52	2-18-52	0-4-53	5-29-53	3-18-54	5-14-53	3-4-52	3-9-52	2-12-53
Sex	Male	Male	Female	Male	Male	Male	Male	Male	Male	Male
Weight (pounds)	180			123	153	176	130			145
Snout to fork tail	2,168	2,184	2,219	2,232	2,244	2,262	2,288	2,293	2,302	2,329
Snout to upper tail notch	2,000			2,072	2,071		2,108			
Snout to inside 1st dorsal	644	711	721	720	689		730			
Snout to inside pectoral	703			778	746		751			
Snout to inside pelvic	724	786	790	785	760		803			
Snout to posterior edge of opercle										
Snout to anterior edge orbit	716	732	736	767	746		784			797
Orbit diameter	440			514	495		527			
Anterior edge orbit to posterior edge opercle	61	41	38	57	56		55	39	42	
Iris to fork of tail	1,762	1,743	1,753	1,745	1,769	1,787	202	1,779	1,830	1,834
Anterior edge orbit to fork of tail	1,667			1,661	1,693		1,706			
Length of mandible	294			285	294		305			
Orbit width opposite tip of mandible	35			37	29		30			45
Orbit depth opposite tip of mandible										
Depth of head	203			158	185		167			
Greatest body depth	394	384	351	301	361	397		360	364	370
Body width tip pectoral	247			203	247	245				
Body depth at vent						352				
Anal groove to inside anal	41			51	42	59				
Dorsal height longest anterior ray	306	295		289	298		305	314	297	265
Dorsal height 20th ray	70			42	70		61			46
Dorsal length base	1,090			1,057	1,094		1,088			1,118
Dorsal height	78	75	77	75	81		90	84		71
Dorsal length base	92			89	91		101			
Anal height	257	251	257	230	255		261	257	253	242
Anal length base	350			324	363		322			
Pectoral length	412	392		412	400		447	412	435	389
Pelvic length				310	357		362			292
Ventral spread	810			790	855		875		853	
Space 1st and 2d dorsals	30			53	43		207			30
Space 1st and 2d anals	64			63	52		72			
Dorsal fin folds against side	Yes			Yes	Yes		Yes			
Number stripes on sides	8						14			
Number free spines between dorsals	0			0	0		0			0

See Footnotes at end of table.

APPENDIX TABLE 1-E.—Original data and morphometric measurements of 68 specimens of *Makaira ampla*, by *POFI*—Con

[Measurements in millimeters]

Item	No. 21	No. 22	No. 23	No. 24	No. 25	No. 26	No. 27	No. 28	No. 29	No. 30
Latitude	15°30' S.	7°06' N.	5°43' N.	8°07' N.	6°13' N.	0°02' N.	9°52' N.	6°13' N.	2°12' S.	3°11' N.
Longitude	149°30' W.	152°11' W.	150°06' W.	149°57' W.	131°00' W.	179°48' E.	151°12' W.	131°00' W.	150°20' W.	130°17' W.
Date taken	2-23-53	10-25-52	8-13-52	8-11-52	11-13-52	2-18-52	5-3-53	11-13-52	8-21-52	11-6-53
Sex	Male	Male	Male	Male	Male	?	?	?	?	Ma
Weight (pounds)	156	170	170	176	?	?	175	?	185	?
Tip snout to fork tail	2,330	2,350	2,374	2,377	2,382	2,402	2,417	2,422	2,435	2,435
Tip snout to upper tail notch							2,235			
Tip snout to inside 1st dorsal		736	785	821	776	783	762	782	816	816
Tip snout to inside pectoral							837			
Tip snout to inside pelvic		780	882	903	843	874	852	840	953	916
Tip snout to posterior edge opercle	775	733	823	832	788	789	835	792	854	816
Tip snout to anterior edge orbit							552			
Orbit diameter	41		60	47	38	39	57	38	39	39
Posterior edge orbit to posterior edge opercle							226			
Naris to fork of tail	1,853	1,908	1,853	1,842	1,899	1,899	1,880	1,930	1,904	1,916
Posterior edge orbit to fork of tail							1,808			
Length of mandible							320			
Sword width opposite tip mandible	33						38			
Sword depth opposite tip mandible										
Depth of head							160			
Greatest body depth	383	401	371	414	389	408		373	426	414
Body width tip pectoral										
Body depth at vent.										
Ventral groove to inside anal										
1st dorsal height longest anterior ray	298	337	302	294	348	300	288	348	296	316
1st dorsal height 20th ray	58						50			
1st dorsal length base	1,116						1,062			
2d dorsal height	80				80		82	97	78	80
2d dorsal length base							106			
1st anal height	242	280	271	257	296	274	259	308	226	216
1st anal length base							346			
Pectoral length	415	446	421	437	440	421	428	470	494	416
Pelvic length	364						257			
Caudal spread		905					850			
Interspace 1st and 2d dorsals	56						110			
Interspace 1st and 2d anals	85						99			
Pectoral fin folds against side	Yes						Yes			
Number stripes on sides	13-14						0			
Number free spines between dorsals	0						0			

Item	No. 31	No. 32	No. 33	No. 34	No. 35	No. 36	No. 37	No. 38	No. 39	No. 40
Latitude	6°40' S.	8°07' N.	3°23' N.	8°14' N.	Hawaii 1-23-53	9°20' S.	5°52' N.	9°01' S.	9°20' S.	5°03' N.
Longitude	160°03' W.	149°57' W.	130°29' W.	120°32' W.		120°53' W.	120°11' W.	131°24' W.	120°53' W.	150°05' W.
Date taken	3-4-52	8-11-52	11-11-52	10-19-52	1-23-53	3-15-54	10-22-52	3-18-54	3-15-54	5-15-54
Sex	Male	Male	?	?		Male	Female	Male	Male	Male
Weight (pounds)		205	184			207		183	173	216
Tip snout to fork tail	2,465	2,477	2,479	2,517	2,528	2,538	2,540	2,550	2,579	2,588
Tip snout to upper tail notch						2,349			2,396	2,416
Tip snout to inside 1st dorsal	826		855	872		789	790		838	838
Tip snout to inside pectoral						861			927	927
Tip snout to inside pelvic	889		910	925			879		924	924
Tip snout to posterior edge opercle	853		860	854	867	867	813		899	899
Tip snout to anterior edge orbit						569			600	600
Orbit diameter	43	45	47	42	42	58	40		61	61
Posterior edge orbit to posterior edge opercle						240			238	238
Naris to fork of tail	1,938	1,957	1,940	1,972	1,985	1,994	2,039	1,998	2,010	2,010
Posterior edge orbit to fork of tail						1,911			1,918	1,918
Length of mandible									360	360
Sword width opposite tip mandible										
Sword depth opposite tip mandible					35				35	35
Depth of head						25			23	23
Greatest body depth	416	404	398	419	396	213	448		205	205
Body width tip pectoral						404		407	392	392
Body depth at vent.						269		231	228	228
Ventral groove to inside anal						366		332	334	334
1st dorsal height longest anterior ray	332	311	319			58		68	50	50
1st dorsal height 20th ray					343	344		333	308	308
1st dorsal length base					63	69			58	58
2d dorsal height	95		102	81	87	87	96		78	78
2d dorsal length base					105	105			109	109
1st anal height	293	262	282	272	272	289	296		253	253
1st anal length base						380			357	357
Pectoral length	466	431	427	429	429	452	513		456	456
Pelvic length					282	382			284	284
Caudal spread	894			873		905	972		883	883
Interspace 1st and 2d dorsals					65	40			51	51
Interspace 1st and 2d anals					74	74			92	92
Pectoral fin folds against side					Yes	Yes			Yes	Yes
Number stripes on sides					8	Ca. 14			Ca. 13	Ca. 13
Number free spines between dorsals					0	0			0	0

See footnotes at end of table.

[Measurements in millimeters]

Item	No. 41	No. 42	No. 43	No. 44	No. 45	No. 46	No. 47	No. 48	No. 49	No. 50
Latitude	1°59' S.	5°15' N.	2°46' N.	1°41' S.	1°41' S.	0°30' S.	1°14' S.	2°51' N.	3°30' N.	3°23' N.
Longitude	120°03' W.	110°17' W.	155°10' W.	140°02' W.	140°02' W.	169°52' W.	150°51' W.	150°04' W.	170°09' W.	130°29' W.
Date taken	10-29-52	3-5-54	2-2-52	8-18-52	9-3-52	6-2-53	11-5-52	5-8-53	6-6-53	11-11-52
Sex	Male	Female	Female	?		Female	Female	?	Female	Female
Weight (pounds)				320	367			312	305	
p snout to fork tail	2,602	2,907	2,695	2,805	2,853	2,856	2,881	2,943	2,953	2,984
p snout to upper tail notch		2,414				2,850		2,709		
p snout to inside 1st dorsal	805	820		988	965	967	972	967		1,024
p snout to inside pectoral		894				966		1,028		
p snout to inside pelvic	875	924		1,032	1,136	963	1,032	1,048		1,109
p snout to posterior edge opercle	815	893	938	982	1,016	974	977	1,021		1,025
p snout to anterior edge orbit		595				640		674		
orbit diameter	43	51		60	58	63	42	61	70	48
anterior edge orbit to posterior edge opercle		247				271		286	294	
iris to fork of tail	2,124	2,034	2,086	2,180	2,230	2,244	2,264	2,305	2,332	2,332
anterior edge orbit to fork of anal fin		1,961				2,153		2,208	2,252	
length of mandible		329				362		377	380	
snout width opposite tip of mandible		40				45		44	49	
snout depth opposite tip of mandible		27								
depth of head		233				225		292	209	
greatest body depth	423	462	447	501	554	513	497		542	526
body width at tip of pectoral		280				309			359	
body depth at vent		397				59			41	
ventral groove to inside anal fin		61								
dorsal height longest anterior ray	311	367	381	376	325	347	401	373	399	404
dorsal height 20th ray		61				35		80	58	
dorsal length base		1,262				1,350		1,373		
dorsal height	72	91				85	102	100		85
dorsal length base		110				120		110		
anal height	239	234		317	267	296	341	285	377	342
anal length base		406				368		413		
total length	477	528	485	582	581	546	521	556	545	496
caudal length		418						370	344	
caudal spread		992				1,074	1,020	1,062		
space between 1st and 2d dorsals		28				44		80		
space between 1st and 2d anals		47						104	101	
total fin folds against side		Yes				Yes		Yes	Yes	
number of stripes on sides		11						14	13	
number free spines between dorsals						0		0	0	

see footnotes at end of table.

APPENDIX TABLE 1-E.—Original data and morphometric measurements of 68 specimens of *Makaira ampla*, by POFI—C

(Measurements in millimeters)

Item	No. 60	No. 61	No. 62	No. 63	No. 64	No. 65	No. 66	No. 67	No. 68
Latitude	7°57' N.	2°38' N.	3°06' N.	1°00' S.	2°10' S.	5°15' N.	2°42' S.	4°10' N.	11°1' N.
Longitude	169°48' W.	169°59' W.	150°12' W.	120°19' W.	112°11' W.	149°55' W.	155°03' W.	168°30' W.	168°30' W.
Date taken	6-9-53	6-5-53	8-16-52	10-27-52	3-10-52	2-1-53	2-6-52	3-12-52	3-12-52
Sex	Female	Female	?	?	Female	?	Female	?	?
Weight (pounds)	540	540	605	645	540	540	540	540	540
Tip snout to fork tail	3,342	3,402	3,419	3,445	3,521	3,521	3,565	3,766	3,766
Tip snout to upper tail notch	3,082	3,152			3,290	3,290			
Tip snout to inside 1st dorsal	1,037	1,083	1,126	1,139	1,162	1,162			
Tip snout to inside pectoral	1,128	1,170			1,238	1,238			
Tip snout to inside pelvic	1,139	1,207	1,234	1,241	1,277	1,277			
Tip snout to posterior edge opercle	1,128	1,188	1,146	1,150	1,250	1,250	1,198		
Tip snout to anterior edge orbit	751	784			868	868			
Orbit diameter	59	70	69	45	65	41	42	41	41
Posterior edge orbit to posterior edge opercle	318	334			317				
Naris to fork of tail	2,620	2,609	2,690	2,720	2,682	2,812	2,824	3,096	3,096
Posterior edge orbit to fork of tail	2,532	2,548			2,588				
Length of mandible	396	423			442				
Sword width opposite tip mandible	50	55			54	58			
Sword depth opposite tip mandible					40				
Depth of head	275	318			272				
Greatest body depth	603	631	597	608	585	655	683	740	740
Body width tip pectoral		286			364				
Body depth at vent.					524				
Ventral groove to inside anal	73	69			82				
1st dorsal height longest anterior ray	453	407	432	462	436	359	458	506	506
1st dorsal height 20th ray	58	50			53	55			
1st dorsal length base	1,654	1,641			1,631	1,556			
2d dorsal height	110	108		120	108	99			
2d dorsal length base	129	125			140				
1st anal height	393	408	408	388	400		443	478	478
1st anal length base	507	456			517				
Pectoral length	618	632	583	635	637	717	597	696	696
Pelvic length	395	368			280	272			
Caudal spread	1,087	1,264			1,232		1,283	1,450	1,450
Interspace 1st and 2d dorsals	58	56			80	162			
Interspace 1st and 2d anals	106	146			129	226			
Pectoral fin folds against side	Yes	Yes			Yes	Yes			
Number stripes on sides		(*)			Ca. 15				
Number free spines between dorsals	0					0			

1 Not visible 2 hours after death.

2 Approximate; tip of snout broken.

3 Includes estimate of 30 mm. for broken snout.

4 About 14 stripes appeared faintly about 1 hr. after death—these dark or brown on the sides and lighter on the back.

5 Includes estimate of 10 mm. for broken snout.

6 Base of 1st dorsal includes 2 disconnected spines.

APPENDIX TABLE 2-A.—Original data and morphometric measurements of two specimens of *Tetrapturus angustirostris* taken in Hawaiian waters

(Measurements by the Hawaiian Division of Fish and Game; in millimeters)

Item	No. 1	No. 2
Date taken	3-20-50	3-18-50
Sex	?	?
Weight (pounds)	47	50
Tip snout to fork tail	1,751	1,857
Orbit diameter	39	40
Naris to fork tail	1,593	1,645
Greatest body depth	208	219
1st dorsal height longest anterior ray	211	229
1st dorsal height 20th ray	173	174
1st dorsal length base	1,077	1,150
Pectoral length	220	211

APPENDIX TABLE 2-B.—Original data and morphometric measurements of five specimens of *Istiompax marlin* taken in Hawaiian waters

(Measurements by the Hawaiian Division of Fish and Game; in millimeters)

Item	No. 1	No. 2	No. 3	No. 4	No. 5
Date taken	6-6-50	4-12-50	4-11-50	3-29-50	4-11-50
Sex	?	?	?	?	?
Weight (pounds)	270	341	305	468	468
Tip snout to fork tail	(2,562)	(2,835)	(2,970)	(3,149)	(3,149)
Orbit diameter	44	46	42	47	47
Naris to fork tail	1,974	2,195	2,305	2,450	2,450
Greatest body depth	525	570	523	643	643
1st dorsal height longest anterior ray	286	316	353	324	324
1st dorsal height 20th ray	66	68	60	65	65
1st dorsal length base	1,116	1,146	1,810	1,883	1,883
Pectoral length			580		

1 Measurements in parentheses estimated from regression data of 3-E.

APPENDIX TABLE 2-C.—Original data and morphometric measurements of 80 specimens of *Makaira audax* taken in Hawaiian waters

[Measurements by the Hawaiian Division of Fish and Game; in millimeters]

Item	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
Specimens taken.....	3-24-50	3-17-50	3-24-50	3-22-50	3-20-50	-----	3-29-50	7-5-50	-----	6-6-50
Weight (pounds).....	?	?	?	?	?	17	?	Male	?	?
Snout to fork tail.....	32	41	42	58	68	81	78	80	80	94
Orbit diameter.....	(1,665)	(1,717)	(1,792)	(1,985)	(1,996)	(2,003)	(2,105)	(2,109)	(2,134)	(2,149)
Pis to fork of tail.....	34	36	39	42	37	41	40	40	42	42
Snout to fork of tail.....	1,240	1,282	1,343	1,499	1,508	1,514	1,596	1,600	1,620	1,632
Snout to fork of tail.....	223	235	236	279	260	304	295	306	306	306
Snout to fork of tail.....	224	239	299	332	312	370	297	370	297	367
Snout to fork of tail.....	147	167	155	105	180	105	106	129	138	107
Snout to fork of tail.....	803	793	866	974	933	916	967	977	975	1,009
Snout to fork of tail.....	282	310	292	374	361	376	382	376	420	413

Item	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16	No. 17	No. 18	No. 19	No. 20
Specimens taken.....	6-6-50	3-22-50	7-5-50	3-23-50	6-6-50	6-6-50	6-22-50	4-12-50	6-6-50	6-5-50
Weight (pounds).....	?	Female	Male	?	?	?	?	?	Female	?
Snout to fork tail.....	85	95	90	110	89	104	94	110	110	100
Orbit diameter.....	(2,160)	(2,184)	(2,211)	(2,227)	(2,250)	(2,275)	(2,292)	(2,302)	(2,307)	(2,312)
Pis to fork of tail.....	43	43	43	41	42	41	42	44	44	44
Snout to fork of tail.....	1,641	1,660	1,682	1,695	1,714	1,734	1,745	1,756	1,760	1,764
Snout to fork of tail.....	303	325	310	338	296	319	315	345	338	328
Snout to fork of tail.....	346	379	354	361	338	387	336	413	424	388
Snout to fork of tail.....	91	-----	105	108	88	112	110	116	124	117
Snout to fork of tail.....	1,010	982	1,000	993	1,090	1,068	1,062	1,088	1,134	1,116
Snout to fork of tail.....	390	415	395	452	359	390	397	487	434	443

Item	No. 21	No. 22	No. 23	No. 24	No. 25	No. 26	No. 27	No. 28	No. 29	No. 30
Specimens taken.....	6-5-50	6-21-50	6-6-50	7-5-50	6-6-50	7-5-50	7-5-50	6-5-50	3-23-50	3-31-50
Weight (pounds).....	?	?	Female	Male	Female	Female	Female	Female	?	Female
Snout to fork tail.....	111	161	125	124	110	124	129	107	147	164
Orbit diameter.....	(2,319)	(2,344)	(2,366)	(2,405)	(2,412)	(2,463)	(2,470)	(2,479)	(2,512)	(2,528)
Pis to fork of tail.....	45	48	45	46	46	45	42	47	46	46
Snout to fork of tail.....	1,770	1,790	1,808	1,839	1,845	1,886	1,892	1,899	1,926	1,939
Snout to fork of tail.....	342	369	358	333	318	350	366	342	369	409
Snout to fork of tail.....	411	389	356	373	280	379	396	383	429	435
Snout to fork of tail.....	102	102	86	102	94	118	100	109	105	82
Snout to fork of tail.....	1,055	1,177	1,080	1,038	1,107	1,117	1,159	1,156	1,169	1,201
Snout to fork of tail.....	459	454	349	433	443	470	464	439	435	530

Immature.

Measurements in parentheses estimated from regression data of table 3-E.

* Questionable measurement.

APPENDIX TABLE 2-D.—Original data and morphometric measurements of 27 specimens of *Makaira amplata* taken in Hawaiian waters

[Measurements by the Hawaiian Division of Fish and Game; in millimeters]

Item	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9
Specimens taken.....	4-10-50	7-5-50	4-10-50	4-17-50	5-8-50	6-6-50	4-17-50	5-8-50	4-18-50
Weight (pounds).....	?	Male	?	Female	Female	Female	Female	Female	Female
Snout to fork tail.....	58	147	170	220	260	207	256	330	297
Orbit diameter.....	(1,731)	(2,315)	(2,458)	(2,549)	(2,592)	(2,609)	(2,633)	(2,754)	(2,756)
Pis to fork of tail.....	34	45	45	45	45	45	45	46	46
Snout to fork of tail.....	1,385	1,829	1,938	2,007	2,040	2,053	2,071	2,163	2,165
Snout to fork of tail.....	359?	363	380	412	438	424	472	502	473
Snout to fork of tail.....	217	258	334	332	349	368	389	382	413
Snout to fork of tail.....	77	53	61	64	63	66	54	58	56
Snout to fork of tail.....	860	1,085	1,213	1,252	1,166	1,253	1,268	1,289	1,301
Snout to fork of tail.....	272?	391	441	479	490	469	515	540	540

Item	No. 10	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16	No. 17	No. 18
Specimens taken.....	4-18-50	4-18-50	4-27-50	6-5-50	4-28-50	6-21-50	4-14-50	4-17-50	4-17-50
Weight (pounds).....	Female	Female	Female	Female	Female	Female	Female	Female	Female
Snout to fork tail.....	342	304	332	448	431	426	426	469	433
Orbit diameter.....	(2,800)	(2,821)	(2,839)	(2,932)	(2,944)	(2,962)	(2,969)	(3,024)	(3,026)
Pis to fork of tail.....	46	48	46	49	45	48	48	47	50
Snout to fork of tail.....	2,198	2,214	2,228	2,299	2,308	2,322	2,327	2,369	2,370
Snout to fork of tail.....	459	454	490	541	566	537	513	539	555
Snout to fork of tail.....	365	412	357	433	410	415	386	378	409
Snout to fork of tail.....	39	64	52	61	60	61	41	43	46
Snout to fork of tail.....	1,326	1,332	1,220	1,356	1,399	1,413	1,274	1,325	1,391
Snout to fork of tail.....	505	522	525	542	574	544	536	526	551

See footnote at end of table.

APPENDIX TABLE 2-D.—Original data and morphometric measurements of 27 specimens of *Makaira amplata* taken in Hawaiian waters—Continued

[Measurements by the Hawaiian Division of Fish and Game; in millimeters]

Item	No. 19	No. 20	No. 21	No. 22	No. 23	No. 24	No. 25	No. 26	No. 27
Date taken.....	5-4-50	8-1-50	5-8-50	4-11-50	4-5-50	4-14-50	5-12-50	4-10-50	5-8-
Sex.....	?	Female	Female	Female	Female	Female	Female	Female	Female
Weight.....	458	572	408	564	508	570	568	791	70
Tip snout to fork tail ¹	(3, 127)	(3, 220)	(3, 244)	(3, 245)	(3, 250)	(3, 320)	(3, 363)	(3, 629)	(3, 68)
Orbit diameter.....	50	51	48	50	50	50	47	52	4
Naris to fork of tail.....	2, 447	2, 518	2, 536	2, 537	2, 541	2, 594	2, 627	2, 829	2, 86
Greatest body depth.....	559	627	533	610	570	579	592	685	60
1st dorsal height longest anterior ray.....	412	364	361	383	425	443	410	494	48
1st dorsal height 20th ray.....	54	60	52	43	33	54	54	58	4
1st dorsal length base.....	1, 362	1, 472	1, 451	1, 475	-----	1, 531	1, 495	1, 735	1, 68
Pectoral length.....	565	617	495	560	552	591	617	671	62

¹ Measurements in parentheses estimated from regression data of table 3-E.

APPENDIX TABLE 3-A.—Reduced regression statistics for various morphometric relationships, by species

[Symbols follow Snedecor (1946); X =log total length in cm.; Y =log weight in pounds]

Location	Source of data	N	SX	SY	SX^2	SY^2	SXY	Sx^2	Sy^2
<i>I. marlina:</i>									
New Zealand—Australia.....	Gregory and Conrad (1939) ^{1,2}	12	5.271	5.708	2.380077	3.691712	2.756802	0.064790	0.9764
Central Pacific.....	POFI ³	6	14.686	14.810	35.963524	36.757096	36.307817	.017091	.2010
Hawaii.....	Hawaiian Division Fish and Game, ^{1,2}	6	2.341	2.831	1.102288	1.661375	1.342524	.006231	.0058
<i>M. audax:</i>									
New Zealand—Australia.....	Gregory and Conrad (1939) ^{1,2}	27	12.338	10.504	5.647082	4.255982	4.832820	.009073	.169
New Zealand.....	Morrow (1952a) ¹	48	21.460	112.531	9.027610	264.261669	50.410703	.033202	.444
Central Pacific.....	POFI ³	13	30.672	26.773	72.459840	56.429689	63.510290	.902795	1.231
Hawaii.....	Hawaiian Division Fish and Game, ¹	30	10.294	58.886	3.594782	116.392004	20.421341	.062567	.806
<i>M. amplata:</i>									
Bimini.....	Conrad and LaMonte (1937) ⁴	23	79.075	55.947	271.926081	136.977437	192.575952	.062793	.887
Central Pacific.....	POFI ³	56	133.495	127.410	318.581533	293.195804	304.770010	.350909	3.315
Hawaii.....	Hawaiian Division Fish and Game, ¹	27	12.434	68.580	5.841042	175.673566	31.984950	.114955	1.480
Location	Source of data	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}_{250\ x}$	$\hat{Y}_{300}$
<i>I. marlina:</i>									
New Zealand—Australia.....	Gregory and Conrad (1939) ^{1,2}	0.249563	2.439	2.476	3.85188	-6.919	0.0391	208.0	41
Central Pacific.....	POFI ³	.057874	3.448	2.468	3.38622	-9.208	.0357	199.1	30
Hawaii.....	Hawaiian Division Fish and Game, ^{1,2}	.017050	2.468	2.566	2.73631	-4.187	.0627	-----	36
<i>M. audax:</i>									
New Zealand—Australia.....	Gregory and Conrad (1939) ^{1,2}	.032881	2.457	2.389	3.62405	-6.515	.0449	149.7	28
New Zealand.....	Morrow (1952a) ¹	.099968	2.447	2.344	3.01090	-5.024	.0558	-----	27
Central Pacific.....	POFI ³	.342486	2.359	2.059	3.69078	-6.648	.0502	159.2	31
Hawaii.....	Hawaiian Division Fish and Game, ¹	.215592	2.343	1.963	3.44578	-6.110	.0477	142.3	20
<i>M. amplata:</i>									
Bimini.....	Conrad and LaMonte (1937) ⁴	.227734	2.438	2.432	3.62674	-6.410	.0542	193.7	30
Central Pacific.....	POFI ³	1.045047	2.384	2.275	2.97811	-4.825	.0613	207.5	30
Hawaii.....	Hawaiian Division Fish and Game, ¹	.402590	2.461	2.540	3.50215	-6.079	.0631	208.9	30

¹ Sums of X , X^2 , and XY computed in log of meters.² Sums of Y , Y^2 , and XY computed in log of weight in hundreds of pounds.³ Sums of X , X^2 , and XY computed in log of centimeters.⁴ Sums of X , X^2 , and XY computed in log of millimeters.

APPENDIX TABLE 3-B.—Reduced regression statistics for various morphometric relationships, by species

[Symbols follow Snedecor (1946); X =fork length in cm.; Y =head length in cm.]

Location	Source of data	N	SX	SY	SX^2	SY^2	SXY	Sx^2	Sy^2
<i>marlina:</i>									
New Zealand-Australia.....	Gregory and Conrad (1939)....	12	3347.5	1149.5	960824.67	112924.59	329095.76	27011.6492	2812.0692
Central Pacific.....	POFI.....	9	2571.9	917.8	744995.49	94846.98	265754.50	10032.2000	1251.7756
<i>audax:</i>									
New Zealand-Australia.....	Gregory and Conrad (1939)....	30	8463.0	3037.5	2400373.04	309132.89	861104.33	12960.7400	1586.0150
Central Pacific.....	POFI.....	20	5069.1	1843.0	1318922.51	173745.38	478411.45	34133.7695	3912.9300
<i>ampla:</i>									
Bimini.....	Conrad and LaMonte (1937)...	23	6353.3	2161.3	1779512.43	205521.07	604409.36	24537.6087	2424.5487
Central Pacific.....	POFI.....	58	15165.9	5126.3	4123041.91	474395.33	1397338.84	157446.6891	21309.9561
Location	Source of data	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}_{250x}$	$\hat{Y}_{300x}$
<i>marlina:</i>									
New Zealand-Australia.....	Gregory and Conrad (1939)....	8433.1559	278.958	95.792	0.25582	-17.438	2.928	86.75	102.36
Central Pacific.....	POFI.....	3477.8534	285.766	101.978	.34667	2.912	2.566	89.58	106.91
<i>audax:</i>									
New Zealand-Australia.....	Gregory and Conrad (1939)....	4225.5800	282.100	101.250	.32603	9.277	2.728	90.79	107.09
Central Pacific.....	POFI.....	11293.8850	253.455	92.150	.33087	8.289	3.128	91.01	107.55
<i>ampla:</i>									
Bimini.....	Conrad and LaMonte (1937)...	7392.5214	276.230	93.970	.30127	10.750	3.067	86.07	101.13
Central Pacific.....	POFI.....	56908.6129	261.481	88.384	.36145	-6.128	3.636	84.24	102.31

APPENDIX TABLE 3-C.—Reduced regression statistics for various morphometric relationships, by species

[Symbols follow Snedecor (1946); X =snout to orbit in cm.; Y =length of mandible in cm.]

Location	Source of data	N	SX	SY	SX^2	SY^2	SXY	Sx^2	Sy^2
<i>marlina:</i>									
New Zealand-Australia.....	Gregory and Conrad (1939)....	12	744.1	382.3	47201.65	12664.85	24337.68	1061.2492	485.4092
Central Pacific.....	POFI.....	7	468.1	290.2	31758.01	12210.94	19676.41	455.4943	180.0771
<i>audax:</i>									
New Zealand-Australia.....	Gregory and Conrad (1939)....	29	1960.5	1056.8	133262.19	38963.40	71877.41	725.6297	452.1504
Central Pacific.....	POFI.....	9	556.2	374.8	35217.54	16132.20	23808.67	844.3800	523.8622
<i>ampla:</i>									
Bimini.....	Conrad and LaMonte (1937)...	21	1314.5	599.9	83237.27	17326.69	37917.87	955.8296	189.5487
Central Pacific.....	POFI.....	25	1531.8	865.7	100666.60	31273.67	55941.10	6810.1504	1296.2104
Location	Source of data	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}_{55x}$	$\hat{Y}_{70x}$
<i>marlina:</i>									
New Zealand-Australia.....	Gregory and Conrad (1939)....	631.8942	62.008	31.858	0.59543	-5.063	3.304	27.69	36.62
Central Pacific.....	POFI.....	270.3214	66.871	41.457	.59347	1.771	1.982	34.41	43.31
<i>audax:</i>									
New Zealand-Australia.....	Gregory and Conrad (1939)....	434.0859	67.603	36.441	.59822	-4.000	2.670	28.90	37.88
Central Pacific.....	POFI.....	646.0300	61.800	41.644	.76509	-5.639	2.056	36.44	47.92
<i>ampla:</i>									
Bimini.....	Conrad and LaMonte (1937)...	366.9867	62.595	28.567	.38395	4.534	1.600	25.65	31.41
Central Pacific.....	POFI.....	2897.9296	61.272	34.628	.42553	8.555	1.656	31.959	38.342

APPENDIX TABLE 3-D.—Reduced regression statistics for various morphometric relationships, by species

[Symbols follow Snedecor (1946); X =fork length in cm.; Y =greatest body depth in cm.]

Location	Source of data	N	SX	SY	SX^2	SY^2	SXY	Sx^2	Sy^2
<i>marlina:</i>									
New Zealand-Australia.....	Gregory and Conrad (1939)....	12	3347.5	647.1	960824.67	36748.28	187423.86	27011.6492	1853.4125
Central Pacific.....	POFI.....	7	2030.1	379.9	594384.21	20874.09	111351.36	5626.2086	256.3743
Hawaii.....	Hawaiian Division Fish and Game.	5	1473.7	287.7	437125.11	16669.59	85231.60	2766.7720	115.3320
<i>audax:</i>									
New Zealand-Australia.....	Gregory and Conrad (1939)....	30	8463.0	1342.2	2400373.04	60649.36	381105.30	12960.7400	599.3320
New Zealand.....	Morrow (1952a).....	46	12866.1	2014.3	3612137.27	88823.75	565496.86	13517.0698	619.3046
Central Pacific.....	POFI.....	21	5200.1	791.9	1314184.11	31007.63	201192.09	26515.5381	1145.4581
Hawaii.....	Hawaiian Division Fish and Game.	28	6233.6	891.1	1401800.78	28865.65	200862.70	14023.3172	506.3925
<i>ampla:</i>									
Bimini.....	Conrad and LaMonte (1937)...	23	6353.3	1112.5	1779512.43	55274.25	312813.85	24537.6087	1463.1087
Central Pacific.....	POFI.....	61	16047.7	2706.1	4389237.89	128055.79	747114.53	167456.1379	7740.6620
Hawaii.....	Hawaiian Division Fish and Game.	27	7879.3	1384.1	2343583.77	72774.59	412177.08	44199.7519	1821.5230

APPENDIX TABLE 3-D.—Reduced regression statistics for various morphometric relationships, by species—Continued

[Symbols follow Snedecor (1946); X =fork length in cm.; Y =greatest body depth in cm.]

Location	Source of data	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}_{240\ x}$	$\hat{Y}_{300\ x}$
<i>I. marlina</i> :									
New Zealand-Australia	Gregory and Conrad (1939)....	6909.9225	278.958	53.925	0.25582	-17.438	2.928	46.52	59
Central Pacific	POFI	1174.9329	290.014	54.271	.20883	-6.293	1.484	45.92	56
Hawaii	Hawaiian Division Fish and Game.	434.9020	294.740	57.540	.15719	11.210	3.957	50.51	55
<i>M. audax</i> :									
New Zealand-Australia	Gregory and Conrad (1939)....	2470.6800	282.100	44.740	.19063	-9.037	2.141	38.62	48
New Zealand	Morrow (1952a).....	2101.5289	279.698	43.789	.15547	.304	2.579	39.17	46
Central Pacific	POFI	5098.7952	247.624	37.710	.19229	-9.906	2.947	38.67	47
Hawaii	Hawaiian Division Fish and Game.	2478.3800	222.629	31.825	.17673	-7.520	1.622	36.66	45
<i>M. ampla</i> :									
Bimini	Conrad and LaMonte (1937)...	5507.4915	276.230	48.370	.22445	-13.630	3.287	42.43	53
Central Pacific	POFI	34412.4961	263.077	44.411	.20550	-9.651	3.367	41.72	52
Hawaii	Hawaiian Division Fish and Game.	8260.8160	291.826	51.263	.18690	-3.279	3.332	43.45	52

APPENDIX TABLE 3-E.—Reduced regression statistics for various morphometric relationships, by species

[Symbols follow Snedecor (1946); measurements in cm.; specimens from POFI collection in Central Pacific]

Relationship and species	N	SX	SY	SX^2	SY^2	SXY	Sx^2	Sy^2
X =greatest body depth								
Y =height 1st dorsal								
<i>I. marlina</i>	6	329.4	202.2	18323.84	6935.74	11265.11	239.7800	121.0
<i>M. audax</i>	21	791.9	898.5	31007.63	39045.69	34640.32	1145.4581	602.7
<i>M. ampla</i>	58	2629.1	2010.2	126395.29	72748.00	95315.50	7763.5313	3077.2
X =tip of snout to upper tail notch								
Y =fork length								
<i>I. marlina</i>	7	1834.5	1983.5	486997.19	569335.99	526554.53	6227.1543	7297.0
<i>M. audax</i>	9	2168.3	2349.9	538835.07	632949.73	583992.11	16443.4156	19390.8
<i>M. ampla</i>	25	6095.8	6594.8	1566682.98	1820646.10	1683480.40	70331.8744	80990.6
X =naris to fork of tail								
Y =fork length								
<i>I. marlina</i>	10	2211.7	2855.5	495707.37	825424.45	639618.84	6545.6810	10036.4
<i>M. audax</i>	21	3971.4	5184.8	773558.78	1314676.26	1008316.15	22510.3058	34573.8
<i>M. ampla</i>	61	12430.7	15793.2	2616040.45	4233130.96	3327257.42	82887.9502	144193.8
X =posterior edge orbit to fork of tail								
Y =fork length								
<i>I. marlina</i>	8	1716.8	230.40	373314.74	672623.95	501082.16	4889.4600	8563.1
<i>M. audax</i>	9	1741.6	2349.9	348776.21	632949.73	469790.74	11795.9600	19390.8
<i>M. ampla</i>	26	5100.8	6794.7	1045728.88	1860606.11	1394685.89	45030.3939	84915.7

Relationship and species	Sxy	$\bar{x}$	$\bar{y}$	b	a	s	$\hat{Y}_{40\ x}$ depth	$\hat{Y}_{100\ x}$ depth
X =greatest body depth								
Y =height 1st dorsal								
<i>I. marlina</i>	164.3300	54.900	33.700	0.68534	-3.925	1.498	23.49	40
<i>M. audax</i>	758.3129	37.710	42.786	.66202	17.821	2.302	44.30	60
<i>M. ampla</i>	4402.4721	45.226	34.659	.56709	9.012	3.220	31.70	40
X =tip of snout to upper tail notch								
Y =fork length								
<i>I. marlina</i>	6735.8514	262.071	263.357	1.08169	-.123	1.483	.....	.....
<i>M. audax</i>	17848.9800	240.922	261.100	1.08548	-.416	1.518	.....	.....
<i>M. ampla</i>	75457.1264	243.832	263.792	1.07287	2.192	1.232	.....	.....
X =naris to fork of tail								
Y =fork length								
<i>I. marlina</i>	8067.9050	221.170	285.550	1.23255	12.947	3.397	.....	.....
<i>M. audax</i>	27796.4015	189.114	246.895	1.23483	13.371	3.627	.....	.....
<i>M. ampla</i>	108888.0554	203.782	238.905	1.31568	-8.799	4.414	.....	.....
X =posterior edge orbit to fork of tail								
Y =fork length								
<i>I. marlina</i>	6450.6200	214.600	288.113	1.31929	4.993	2.978	.....	.....
<i>M. audax</i>	15085.0900	193.500	261.100	1.27884	13.644	3.769	.....	.....
<i>M. ampla</i>	61670.2839	196.185	261.335	1.36953	-7.346	4.361	.....	.....

APPENDIX TABLE 4.—Reduced statistics for ratios and mean lengths of various parts, by species

[Symbols used follow Snedecor (1946)]

Species and location	Source of data	N	Minimum	Maximum	SX	SX ²	Sx ²	$\bar{x}$	s
snout to orbit									
head length									
<i>I. marina</i> :									
New Zealand-Australia	Gregory and Conrad (1939)	12	0.598	0.683	7.783	5.054525	0.006601	0.6486	0.02450
Central Pacific	POFI	7	.642	.688	4.610	3.037550	.001536	.6586	.01600
<i>M. audax</i> :									
New Zealand-Australia	Gregory and Conrad (1939)	30	.626	.701	20.057	13.416037	.006595	.6686	.01508
Central Pacific	POFI	9	.638	.699	5.971	3.964641	.003214	.6634	.02143
<i>M. ampla</i> :									
Bimini	Conrad and LaMonte (1937)	23	.637	.694	15.230	10.089880	.004971	.6622	.01503
Central Pacific	POFI	26	.576	.694	17.193	11.382779	.013577	.6613	.02378
height 1st dorsal									
fork length									
<i>I. marina</i> :									
New Zealand-Australia	Gregory and Conrad (1939)	11	.121	.134	1.397	.177657	.000238	.1270	.00488
Central Pacific	POFI	10	.103	.128	1.158	.134552	.000456	.1158	.00755
Hawaii	Hawaiian Division Fish and Game	6	.102	.119	.647	.060039	.000197	.1094	.00810
<i>M. audax</i> :									
New Zealand-Australia	Gregory and Conrad (1939)	30	.147	.185	5.048	.853002	.003592	.1683	.01113
Central Pacific	POFI	25	.151	.198	4.308	.746056	.003701	.1723	.01269
Hawaii	Hawaiian Division Fish and Game	28	.116	.184	4.551	.744995	.005295	.1625	.01400
<i>M. ampla</i> :									
Bimini	Conrad and LaMonte (1937)	23	.118	.161	3.246	.460900	.002791	.1411	.01126
Central Pacific	POFI	63	.111	.148	8.116	1.050914	.005367	.1288	.00930
Hawaii	Hawaiian Division Fish and Game	27	.111	.150	3.560	.472408	.003015	.1319	.01098
pectoral length									
fork length									
<i>I. marina</i> :									
New Zealand-Australia	Gregory and Conrad (1939)	12	.176	.204	2.235	.416825	.000556	.1863	.00711
Central Pacific	POFI	11	.173	.209	2.031	.375995	.000999	.1846	.01054
<i>M. audax</i> :									
New Zealand-Australia	Gregory and Conrad (1939)	30	.166	.216	5.832	1.137588	.003847	.1944	.01152
New Zealand	Morrow (1952a)	47	.175	.220	9.113	1.772563	.005610	.1939	.01104
Central Pacific	POFI	19	.178	.212	3.656	.704853	.001746	.1924	.00985
Hawaii	Hawaiian Division Fish and Game	25	.148	.212	4.627	.861259	.004894	.1851	.01428
<i>M. ampla</i> :									
Bimini	Conrad and LaMonte (1937)	23	.168	.198	4.209	.771899	.001652	.1830	.00867
Central Pacific	POFI	57	.166	.207	10.458	1.924614	.005846	.1835	.01022
Hawaii	Hawaiian Division Fish and Game	26	.153	.196	4.728	.862254	.002485	.1818	.00997
caudal spread									
fork length									
<i>M. marina</i> :									
New Zealand-Australia	Gregory and Conrad (1939)	12	.331	.373	4.183	1.459817	.001693	.3486	.01241
Central Pacific	POFI	8	.336	.371	2.861	1.024495	.001330	.3576	.01489
<i>M. audax</i> :									
New Zealand-Australia	Gregory and Conrad (1939)	30	.284	.379	10.018	3.360392	.015048	.3339	.02278
Central Pacific	POFI	9	.320	.382	3.179	1.127497	.004604	.3532	.02565
<i>M. ampla</i> :									
Bimini	Conrad and LaMonte (1937)	23	.327	.395	8.211	2.936609	.005282	.3670	.01549
Central Pacific	POFI	39	.325	.386	14.213	5.188813	.009083	.3644	.01567
height 1st anal									
height 1st dorsal									
<i>I. marina</i> :									
New Zealand-Australia	Gregory and Conrad (1939)	11	.681	.756	8.558	6.674676	.016552	.7780	.04068
Central Pacific	POFI	8	.751	1.004	6.712	5.678072	.046704	.8390	.08168
<i>M. audax</i> :									
New Zealand-Australia	Gregory and Conrad (1939)	30	.502	.811	20.328	13.878122	.103869	.6776	.05985
Central Pacific	POFI	22	.591	.686	14.211	9.195089	.015429	.6460	.02778
<i>M. ampla</i> :									
Bimini	Conrad and LaMonte (1937)	23	.775	.963	19.621	16.789827	.051408	.8531	.04834
Central Pacific	POFI	58	.764	1.002	50.233	43.659623	.153515	.8661	.05236
pelvic length (cm.)									
<i>I. marina</i> :									
New Zealand-Australia	Gregory and Conrad (1939)	11	.212	.283	277.1	7,036.01	55.6091	25.191	2.358
Central Pacific	POFI	9	.186	.304	233.2	6,141.88	99.4089	26.911	3.525
<i>M. audax</i> :									
New Zealand-Australia	Gregory and Conrad (1939)	30	.230	.373	958.8	30,933.88	290.6320	31.960	3.166
Central Pacific	POFI	12	.220	.387	395.9	13,433.21	371.8092	32.992	6.098
<i>M. ampla</i> :									
Bimini	Conrad and LaMonte (1937)	22	.242	.427	765.7	27,023.19	373.3495	34.805	4.216
Central Pacific	POFI	33	.257	.418	1,111.6	38,052.96	608.8825	33.685	4.432
length 20th ray of 1st dorsal (cm.)									
<i>I. marina</i> :									
Central Pacific	POFI	9	.45	.78	60.8	418.44	7.7022	6.756	.9812
Hawaii	Hawaiian Division Fish and Game	5	.56	.68	30.9	191.85	.8880	6.180	.544
<i>M. audax</i> :									
Central Pacific	POFI	11	.77	1.27	110.4	1,131.88	23.8655	100.36	1.628
Hawaii	Hawaiian Division Fish and Game	24	.82	1.38	255.6	2,762.72	40.5800	106.50	1.328
<i>M. ampla</i> :									
Central Pacific	POFI	35	.35	.85	217.7	1,401.39	47.2960	6.220	1.197
Hawaii	Hawaiian Division Fish and Game	27	.33	.77	148.5	840.31	23.5600	5.500	.971

APPENDIX TABLE 5.—Summary of stomach contents and sexual condition of the *POFI* specimens

Specimen	Stomach contents	Sex	Sexual condition	Specimen	Stomach contents	Sex	Sexual condition
<i>Istiompax</i>				<i>Makaira</i>			
<i>marlina:</i>				<i>ampla—</i>			
No. 1.....	Empty.....	?	No data.	Continued			
No. 2.....	1 aku (30 cm.).....	Male	Maturing.	No. 16.....	Fish remains, including 1 <i>Coryphaena</i> (about 1 cm.).....	Male.....	Milt running from cut testes.
No. 3.....	Empty.....	?	Immature.	No. 17.....	4 small squid (6 cm.); remains of 1 fish (3 cm.)..	do.....	Milt in testes.
No. 4.....	1 <i>Mola</i> (18").....	Male	Not active.	No. 18.....	Empty.....	do.....	No data.
No. 5.....	No data.....	Female	No data.	No. 19.....	1 small unidentified fish.....	do.....	Do.
No. 6.....	2 <i>Mola</i> , 1 squid (8 cm.).....	?	Gonads very thin.	No. 20.....	1 unidentified fish (10 cm.).....	do.....	Milt in testes.
No. 7.....	1 <i>Mola</i> (5 lb.).....	?	Immature.	No. 21.....	Almost empty; fragments of fish; squid remains.	do.....	Do.
No. 8.....	Albacore (94 cm.).....	Female	No data.	No. 22.....	No data.....	do.....	Do.
No. 9.....	Fish remains.....	do.....	Not active.	No. 23.....	3 unidentified fish (about 15 cm. each).....	do.....	Mature.
No. 10.....	Empty.....	?	Immature.	No. 24.....	80% fish; 20% squid.....	do.....	No data.
No. 11.....	Large fish skeleton; 6 vertebrae (5 cm.); fin rays (8").....	Female	Not active.	No. 25.....	No data.....	?	Do.
<i>Makaira</i>				No. 26.....	1 fish (15 cm.).....	?	Very immature.
<i>audax:</i>				No. 27.....	Empty.....	?	No data.
No. 1.....	1 squid; 2 tunas (juvenile).....	?	Immature.	No. 28.....	do.....	?	Immature.
No. 2.....	50% fish; 50% squid.....	?	No data.	No. 29.....	1 <i>Katsuwonus</i> (?) (2 lb.).....	?	No data.
No. 3.....	<i>Auzie</i> and hiramid.....	?	Very immature.	No. 30.....	Empty.....	Male.....	Milt in testes.
No. 4.....	1 fish (100 lb.).....	?	Immature.	No. 31.....	Fish vertebrae.....	do.....	No data.
No. 5.....	Empty.....	?	No data.	No. 32.....	90% fish; 5% squid; 5% crustaceans.	do.....	Slightly running milt
No. 6.....	2 fish remains; 1 tuna-like fish.....	?	Do.	No. 33.....	Empty.....	?	Immature.
No. 10.....	2 tunalike fish (35 and 32 cm.).....	Male	Testes (8 mm. diameter) with milt.	No. 34.....	1 small <i>Coryphaena</i>	?	Very immature.
No. 11.....	1 <i>Auzie</i> (33 cm.); 1 squid with 8 cm. mantle; fish bones.....	Female	Not active (ovary 1 x 4 x 25 cm.).	No. 35.....	50% cephalopods; 50% fish, including 1 <i>Coryphaena</i> (15 cm.).....	Male.....	Milt flows freely when cut; testes enlarged (6 cm. diameter).
No. 12.....	Fish remains.....	Male	Small testes (1 cm. diameter) with milt and fatty appearance.	No. 37.....	Empty.....	Female.....	Immature.
No. 13.....	No data.....	Female	Ovaries enlarged, but not near spawning (6 x 3 cm. diameter).	No. 38.....	Octopus (¾ lb.).....	Male.....	Milt in testes.
No. 14.....	Squid and scombrid fish.....	do.....	Immature.	No. 39.....	90% fish; 10% cephalopods.	do.....	Testes with running milt when cut (about 4 cm. diameter).
No. 15.....	Empty.....	?	No data.	No. 40.....	Empty.....	do.....	No milt visible.
No. 16.....	do.....	?	Immature.	No. 41.....	2 baits.....	do.....	Milt in testes.
No. 17.....	Flying fish remains; carapace of large shrimp.....	?	Do.	No. 42.....	5 <i>Auzie</i> (33 cm., avg.).....	Female.....	Not active (ovary 3 cm. diameter).
No. 18.....	Empty.....	Female	Not quite mature.	No. 44.....	2 pieces bait; 1 small unidentified fish.....	?	No data.
No. 19.....	No data.....	do.....	Immature.	No. 45.....	Empty.....	?	Do.
No. 20.....	<i>Mola</i> (45 cm.); fish remains.....	do.....	Ova not visible to naked eye.	No. 46.....	2 <i>Katsuwonus</i> (1 about 65 cm., other digested).	Female.....	Gonad with thick wall; inside like nonspawning tuna ovary.
No. 21.....	1 small scombrid.....	?	Immature.	No. 47.....	Empty.....	do.....	No data.
No. 22.....	No data.....	Female	No data.	No. 48.....	do.....	?	Do.
No. 23.....	40% fish; 60% squid.....	?	Mature.	No. 49.....	do.....	Female.....	Do.
No. 24.....	Empty.....	?	No data.	No. 50.....	No data.....	do.....	Mature.
No. 25.....	do.....	?	Do.	No. 51.....	do.....	do.....	Not ripe.
<i>Makaira</i>				No. 52.....	Empty.....	do.....	No data.
<i>ampla:</i>				No. 53.....	do.....	do.....	Gonad enclosed in head connective tissues; semicylindrical; does not appear fatty as males.
No. 2.....	2 squid (5 cm.); remains 1 small <i>Mola</i>	?	Immature.	No. 54.....	1 tuna (42 cm.).....	do.....	Not active (ovary about 2½ cm. diameter).
No. 3.....	20% squid; 80% fish; remains 1 surgeonfish (5 cm.).....	Male	Milt in center gonad.	No. 55.....	No data.....	do.....	Eggs visible to naked eye.
No. 4.....	45% fish; 55% squid.....	do.....	Young.	No. 56.....	do.....	do.....	No data.
No. 5.....	100% fish.....	do.....	Little milt.	No. 58.....	1 bait.....	do.....	Do.
No. 6.....	Empty.....	do.....	No data.	No. 60.....	No data.....	do.....	Do.
No. 7.....	Bait; squid; 2 scombrids (6").....	Female	Immature.	No. 61.....	Empty.....	do.....	Do.
No. 8.....	Tunicates.....	Male	Maturing.	No. 62.....	do.....	?	Do.
No. 9.....	3 squid (6 cm. each); 3 fish (10-15 cm. each) well digested.....	do.....	Milt spurts from duct.	No. 63.....	Fish bones and squid.....	?	Immature.
No. 10.....	1 tunalike fish (20 cm.).....	?	No data.	No. 64.....	1 <i>Katsuwonus</i> (66 cm.).....	Female.....	Not active (ovary 2 x 4 cm. diameter)
No. 11.....	1 gempylid (30 cm.); 2 fish (4 cm. each).....	do.....	Milt in lumen of testes.	No. 66.....	1 <i>Katsuwonus</i> (28 cm.).....	do.....	No data.
No. 12.....	No data.....	do.....	Maturing.	No. 67.....	1 <i>Katsuwonus</i> (8 lb.).....	?	Spent.
No. 13.....	Fish vertebrae; squid; 2 (4") fish.....	Female	No data.	No. 68.....	No data.....	Female.....	Not active.
No. 14.....	Bait.....	Male	Do.				
No. 15.....	Fish remains, including 2 <i>Mola</i> (1 about 30 cm.).....	do.....	Testes pink with fatty appearance, milt in central duct.				

STRASBURG, Donald W.

1957. Notes on the respiration of small

Remora remora. Copeia 1957 (1): 58-60.

NOTES ON THE RESPIRATION OF SMALL REMORA REMORA.—On a recent equatorial cruise of the U. S. Fish and Wildlife Service vessel HUGH M. SMITH numerous specimens of the white-tipped shark *Pterolamiops longimanus* (Poey) were taken by handline. On March 22-23, 1956, at approximately 1°N. latitude and 140°W. longitude, two six-foot sharks bearing small sucker fish, *Remora remora* (Linnaeus), were landed. Three of the latter were transferred to a large plastic tub immediately after the sharks were captured. The tub was supplied with running sea water pumped directly from the ocean; thus the water had essentially the same temperature and dissolved oxygen characteristics as the natural environment. Despite these supposedly favorable conditions the remoras consistently evidenced peculiar respiratory behavior, not all of which could be ascribed to the shock of capture, handling, or confinement.

Upon being placed in the tub each remora at first swam slowly about, but very soon attached its sucking disc to the side of the tub just at the water's edge. The mouth and part of the head were exposed to the air, and respiratory movements consisted of rapid gulps in which some air was taken in and some water forcibly expelled from the mouth. The fish could be manually moved down the side of the tub with difficulty but usually returned quickly to the surface when not restrained. In those instances where fish remained submerged, their opercular breathing movements ranged from 135 to 244 expirations per minute (Table I). This rate appears to be relatively high, for the highest value in Norman's list (1949, A History of Fishes, p. 43) of rates for various species is 150 respirations per minute for the minnow *Phoxinus* and the stickleback *Gasterosteus*.

By chance it was found that a jet of water aimed at the remoras' open mouths caused the respiratory rate to decrease markedly, and the fish could then be pushed down the side of the container with little difficulty. They remained submerged as long as water was flowing over them, but rheotactic behavior was not indicated since they did not orient themselves to the current when its direction was changed.

By varying the rate of water flow a point was found at which the fish ceased all opercular movements and other external signs of respiration. Water was administered by a length of quarter-inch glass tubing placed about an eighth of an inch in front of the fish's mouth and connected to a faucet by rubber tubing. The rate of flow could be controlled quite easily and was measured by timing the interval required to fill a 1000 ml. volumetric flask. Several tests were made to determine the rate of flow necessary to stop external respiratory movements, and the results are presented in Table I. Of the various tests, numbers 3 to 8 are not given further consideration, as changing water temperature and other variables invalidated them for comparative purposes.

With flowing water, the volume of flow required to stop respiratory gill movements increased with increase in fish size (mean values of tests 1 and 2). Without flowing water, the number of respirations per minute decreased with increase in fish size. A measure of the interrelationship between these two phenomena can be obtained by dividing the flow rate (in ml. per minute) by the respiratory rate (in respirations per minute) giving an index in terms of milliliters of water per single respiration (Table I, column 5). These values are only relative since not all water aimed at the fish's mouth is presumed to enter. When the mean milliliter-per-respiration values (tests 1 and 2) are plotted against fish volume an almost perfect linear relationship is apparent. This admittedly should obtain because respiratory volume varies with the size of the branchial and buccal cavities, which in turn is dependent on the size of the fish. When respiratory volume is expressed as a percentage of fish volume the mean values of all three fish (tests 1 and 2, column 8) are 40 percent, this again being only a relative figure. Assuming that only half of the water from the jet actually enters the mouth, and that the respiratory rate in standing water is about 200 respirations per minute, then in one minute a small remora would pass a quantity of water equivalent to 40 times its own volume over its gills, certainly a remarkable achievement.

TABLE I
RESPIRATORY DATA FOR *Remora remora*
Fish A, B, and C were tested simultaneously in Test 1 and again in Test 2.

1 Fish, with its standard length and displacement volume	2 Test No.	3 Water temperature in degrees F.	4 Respirations per minute with no current applied	Rate of water flow required to stop opercular movements			
				5 In milliliters per minute	6 In miles per hour ¹	7 In ml. per respiration ²	8 Ml. per respiration as percent of fish volume ³
A 81 mm. 7.1 ml.	1	76.8	244	638	0.75	2.6	37
	2	76.8	244	747	0.88	3.1	44
	Mean		244	692	0.82	2.8	40
B 98 mm. 11.9 ml.	1	76.8	236	1143	1.34	4.8	40
	2	76.8	236	1161	1.37	4.9	41
	Mean		236	1152	1.36	4.8	40
	3	78.6	200	—	—	—	—
	4	77.0	210	—	—	—	—
	5	77.0	150	1186	1.40	7.9	66
	6	77.1	147	1215	1.43	8.3	70
	7	77.2	135	1136	1.34	8.4	71
	8	76.3	217	1095	1.29	5.0	42
	Grand mean		191	1156	1.36	6.6	55
C 103 mm. 14.5 ml.	1	76.8	203	1357	1.60	6.7	46
	2	76.8	203	1007	1.18	5.0	34
	Mean		203	1182	1.39	5.8	40

¹ Calculated from flow per unit time through quarter-inch glass tubing.

² Calculated by dividing the figure in column 5 by that in column 4.

³ The figure in column 7 as a percent of the volume given in column 1.

The fact that when remoras are not provided with an artificial stream of water the breathing rate is higher for small individuals suggests that smaller specimens either require more oxygen, have less efficient gills, or relatively smaller buccal and branchial cavities. It has already been demonstrated that the relative amount of water passed per resting respiration is exactly proportional to fish volume, a not unexpected situation, eliminating one possible reason for the higher rate of small fish. Of the remaining two, less efficient gills or greater respiratory need, the latter is more attractive as generally metabolic rates are higher in smaller individuals of a given species.

It is difficult to state how much the exciting and debilitating effects of capture and confinement contributed to the behavior outlined above. The first remora taken (Fish B) was confined for 28 hours and apparently was in good condition at the end of this period. The other two were captured 20 hours after Fish B, and were found dead in the tub after 21 hours of confinement. They were under observation for the first 15 hours of this period and appeared normal throughout that time; they died during the night when the supply of circulating sea water was shut off. All three fish were in a state of excitation

when first placed in the tub but appeared to adjust to the new environment quite rapidly.

Several extrapolations from the tabulated data and the described behavior are worthy of comment. It would appear that remoras may obtain other benefits from shark-riding than just transportation and the chance to dine with a shark. Their aquarium behavior suggests that they may require rapidly moving water to convey dissolved oxygen to their gills, and that they have become so adjusted to this service that an inordinate expenditure of energy (in the form of rapid respiratory movements) is required when in quiet water. Some evidence for this is the fact that Fish B survived a night in circulating sea water whereas Fish A and C died the next night when the water was shut off (Fish B had been preserved in the meantime).

One would expect this limitation to be reflected in either the respiratory anatomy or physiology of *Remora*. Apparently little is known about the physiology of echeneids. Gray (1954, Biol. Bull., 107(2) : 221) has calculated the gill area of *Echeneis naucrates* and ranks the species ecologically with the cutlass fish (*Trichiurus*), the butter fish (*Poronotus*), and other "fishes of moderate activity" living around piers or spending some time resting on the bottom.

Willem (1951, Bull. Inst. Roy. Sci. Nat. Belg., 27(8) : 1-6) noted the unusual development of the respiratory musculature of *Echeneis naucrates* and concluded that the species must pass a considerable volume of water with each expiration which is certainly in accordance with the present findings for *Remora*. Gross examination of the preserved experimental specimens and others caught subsequently revealed no outstanding branchial differences between *Remora* and more generalized fishes.

From these lines of evidence *Remora remora* appears to be somewhat comparable to the Atlantic mackerel (Hall, 1930, Am. Jour. Physiol. 93(2): 420) in that it requires a swift passage of water over its gills and cannot cope with confinement in still water. On the other hand, various echeneids have been maintained in the Honolulu Aquarium for several weeks without difficulty (personal communication from Spencer Tinker, the Director).

When the rate of water flow required to stop opercular movements is expressed in miles per hour, a very peculiar result is obtained (Table I, column 6). It would superficially appear that larger remoras require faster currents than smaller specimens, in contrast to the measurements of respiratory rate and the situation found in nature. In my experience small echeneids are nearly always found attached to moving objects whereas the largest

specimens seen were three-foot *Echeneis naucrates* found free-swimming around piers in the Marshall Islands. The conflict between these observations stems from the fact that computed water speed was derived from flow through glass tubing and not through the fish's buccal cavities. The cross-sectional area of the latter increases with increasing fish size whereas that of the former is constant. Water speed decreases upon leaving the tube orifice and entering the relatively large buccal cavity, the decrease becoming greater with increasing fish size. The speed of water flow calculated for the smallest remora (Fish A) most closely approximates the actual speed through the mouth, whereas those for Fish B and C are increasingly in error.

A final question has to do with whether the speed of flow determined for Fish A can be used as an approximation of the average swimming speed of white-tipped sharks. Efforts to time these sharks as they circled the drifting HUGH M. SMITH were not particularly successful in that the sharks often loitered over garbage, pursued irregular courses, or disappeared from view. A speed of about one mile an hour is certainly within the capabilities of *Pterolamiops longimanus* and may well approximate its normal cruising speed.—DONALD W. STRASBURG, U. S. Fish and Wildlife Service, Honolulu, Hawaii.

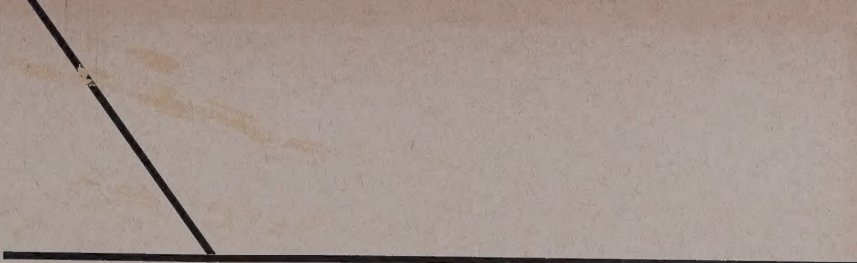
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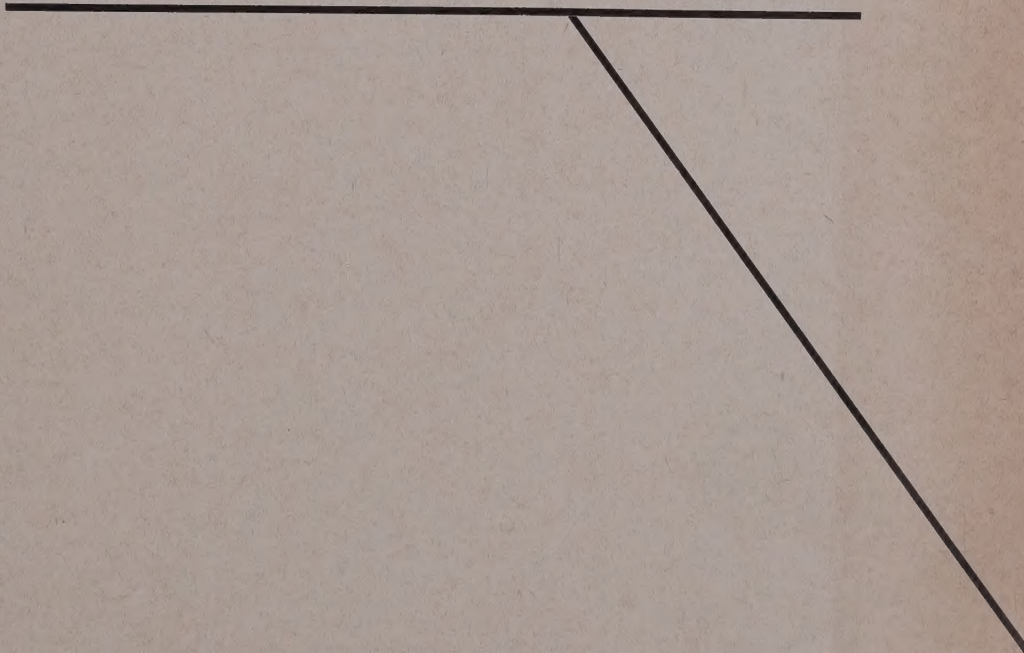
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NUISANCE OR RESOURCE?

S H A R K S

OF THE CENTRAL PACIFIC



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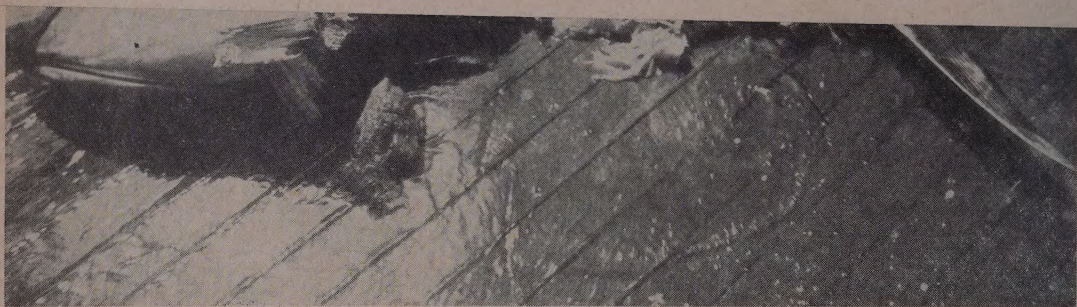


Figure 2.—Longline-caught yellowfin tuna badly damaged by sharks.

SHARKS OF THE CENTRAL PACIFIC...

Nuisance or Resource?

By **DONALD W. STRASBURG**

Fishery Research Biologist
Pacific Oceanic Fishery Investigations
U.S. Fish and Wildlife Service
Honolulu, T. H.

IN MANY parts of the Pacific Ocean, especially in the tropics, fishing and baiting operations are either hampered or made dangerous by the presence of sharks. The shark nuisance may result in loss or damage to the catch, time wasted in untangling or repairing gear, and in rare cases in injury to personnel.

For the past several years the Pacific Oceanic Fishery Investigations of the U.S. Fish and Wildlife Service, with headquarters in Honolulu, has been using longline gear to sample the tuna resources of the Pacific. During the period 1952-1955, POFI longlined from just south of the Aleutian Islands to the Society Islands, and from the west coast of the United States to 180°, the International Date Line.

Besides tuna, marlin, and a few other food fish the catch contained over 6,000 sharks. Of these, about

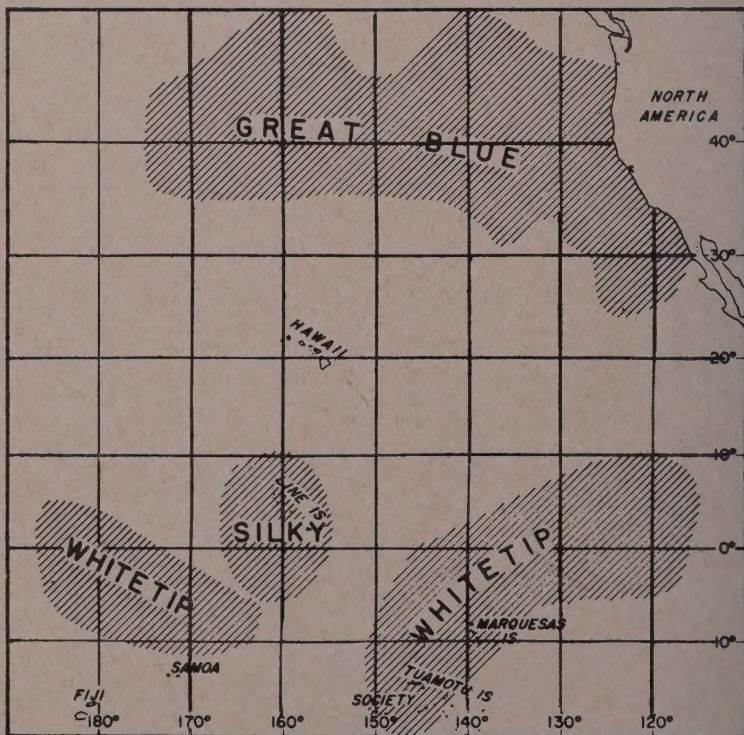


Figure 1.—The central Pacific Ocean showing regions in which FWS found sharks to be abundant and indicating the dominant species.

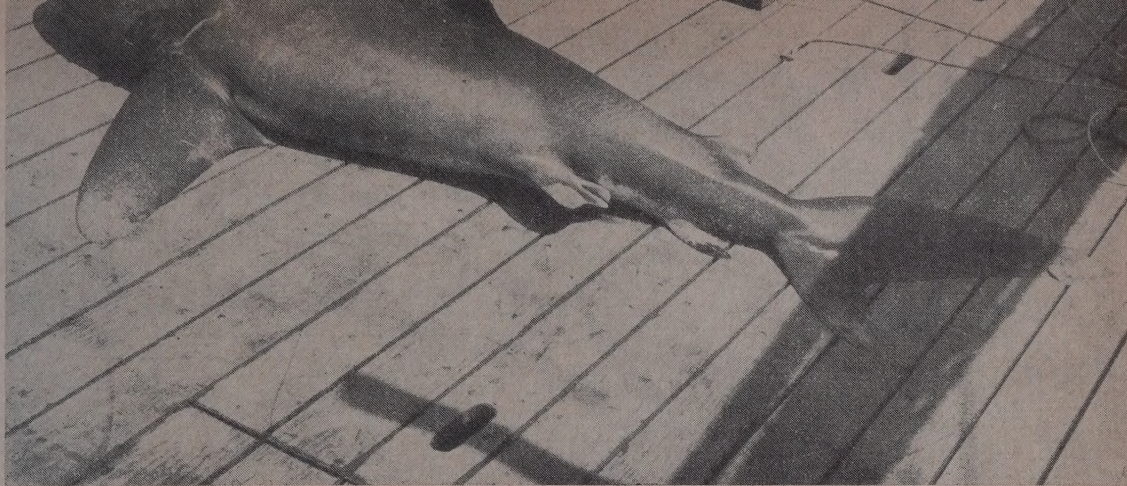


Figure 3.—Whitetip shark caught in equatorial waters by POFI vessel John R. Manning. Note white-tipped fins and heavy body.

2,500 were great blues, 2,200 were silkies, and 1200 were whitetips. The names for the first and last of these are derived from their color, the great blue being blue above and white below, and the whitetip having white-tipped fins. The silky shark's name comes from its skin which is smooth compared to the sandpaper-like covering of other sharks. Besides these three common sharks nine other species including hammerheads, thresher, and makos were taken.

The great blue was not only the most abundant but also the most widely distributed shark captured. Although it ranged from the Aleutians to the Society Islands large catches were made only in the north, particularly in the waters immediately off the U.S. west coast (fig. 1). Great blues were pests in that they fouled lines and tangled nets, but they seemed to do little damage to the tuna catch. Usually less than 1% of the catch was affected, and gen-

erally the damaged tuna were only partly eaten.

As in all sharks, male great blues can be told from females by their possession of finger-like "claspers" on the pelvic fins. Records were kept of the number of males and females captured each day, and it was found that sometimes the catches were composed only of males, and sometimes only of females. A splitting-up of the sexes in this way is probably related to breeding. Catches with a predomi-

Figure 4.—Great blue shark 8½ feet in length. Taken near Equator by the John R. Manning.

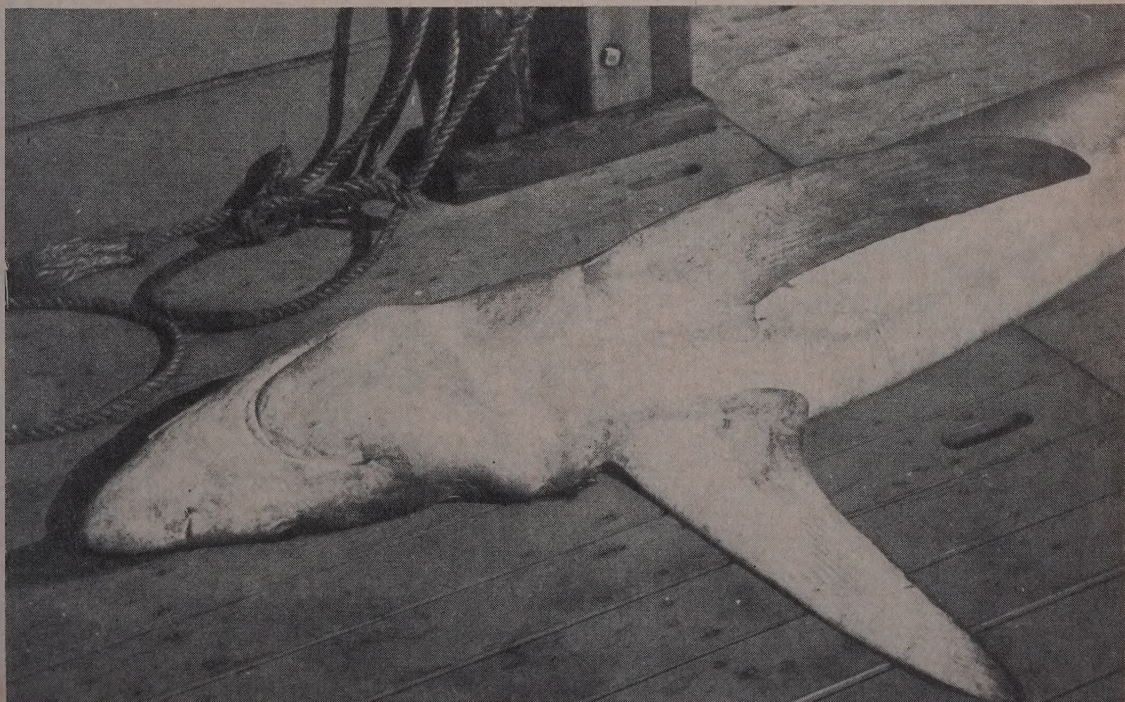




Figure 5.—Dispatching a shark on the deck of the POFI vessel Charles H. Gilbert.

nance of one sex were made in the spring but were most common in the summer. By winter males and females were equally represented in the catch. The great blues appear to have northern "pupping" grounds, the location of which is yet to be discovered.

The whitetip and the silky were mostly equatorial sharks, in fact the silky was only rarely taken outside of a 10-degree band on each side of the Equator. The silky was common near islands whereas the whitetip was more strictly oceanic (fig. 1). Both were guilty of feeding on hooked tuna, and on the average they damaged about 20% of the catch.

In some cases only a small chunk was bitten from the tuna, but more often most of the fish was consumed (fig. 2). Some of POFI's data suggest that both of these sharks may swim fast enough to catch a free-swimming tuna. For one thing both species of sharks are occasionally caught on trolling lines at vessel speeds of 6 to 8 knots, and for another, one bigeye tuna captured alive bore a pair of large U-shaped scars suspiciously resembling shark jaws in shape.

As can be seen from figure 3 the whitetip is a stout-bodied shark, and the silky has very similar body proportions. Most whitetips caught measured from 5 to 7 feet in total length, with their weight running from about 50 to 125 pounds. Silkies were usually about 7 feet long with weights of from 110 to 160 pounds. In con-

trast to these two species, the great blue is quite slender (fig. 4). The larger great blues averaged about 8 feet in length, but weighed only 125 pounds.

An idea of shark abundance can be obtained by comparing the catch-rates of sharks and yellowfin tuna. In the case of yellowfin a daily catch of six or more tuna per hundred hooks is considered commercially profitable. POFI's northern catches of sharks have run as high as 35 great blues per hundred hooks, and near the Line Islands (fig. 1) as great as 61 silkies per hundred hooks. Although these figures represent exceptional catches they nevertheless indicate that high seas sharks may be quite abundant.

In common with other tuna fishermen, POFI personnel were not trying to catch sharks. The hooks, bait, and lines were all designed to catch tuna, and fishing was done at depths and in regions where these fish were thought to be abundant. Nevertheless the hungry sharks found the bait irresistible, and hooked themselves with no difficulty.

During periods of good tuna fishing there was little time for handling sharks, and many of those hooked were not brought aboard. In some instances the lines were cut and the sharks set free, while in others the animals were killed and discarded (fig. 5). In no case were sharks brought back to port for sale or proc-

essing. Markets for shark products (livers, fins, skin, and meat) exist in various parts of the world, but in Hawaii the limited demand is satisfied by imports.

Shark livers were formerly valued for their oil which is high in Vitamin A. Not only is this vitamin now synthesized artificially but its content tends to be low in tropical sharks; for these reasons the liver oil would probably not sustain a central Pacific shark fishery.

Shark fins and flesh are ingredients of shark fin soup and fish cake, both of which are widely consumed in Hawaii. In recent years, however, marlin and swordfish meat have replaced shark in fish cake, with the result that the Honolulu shark landings have fallen from an average of 21,000 pounds per year during 1944-53 to 200 pounds in 1954 and 12 pounds in 1955. With no sharks being landed, Hawaii-processed fins of course are no longer available.

Local fishermen report that shark numbers have increased since the fishing pressure was removed; this will probably result in more food fish being eaten by sharks and poorer fishing for both sport and commercial fishermen. We are, therefore, faced with the problem of controlling shark numbers to protect our sport and commercial fisheries, or, better yet, of devising some means of utilizing this potentially valuable resource to the benefit of us all. *